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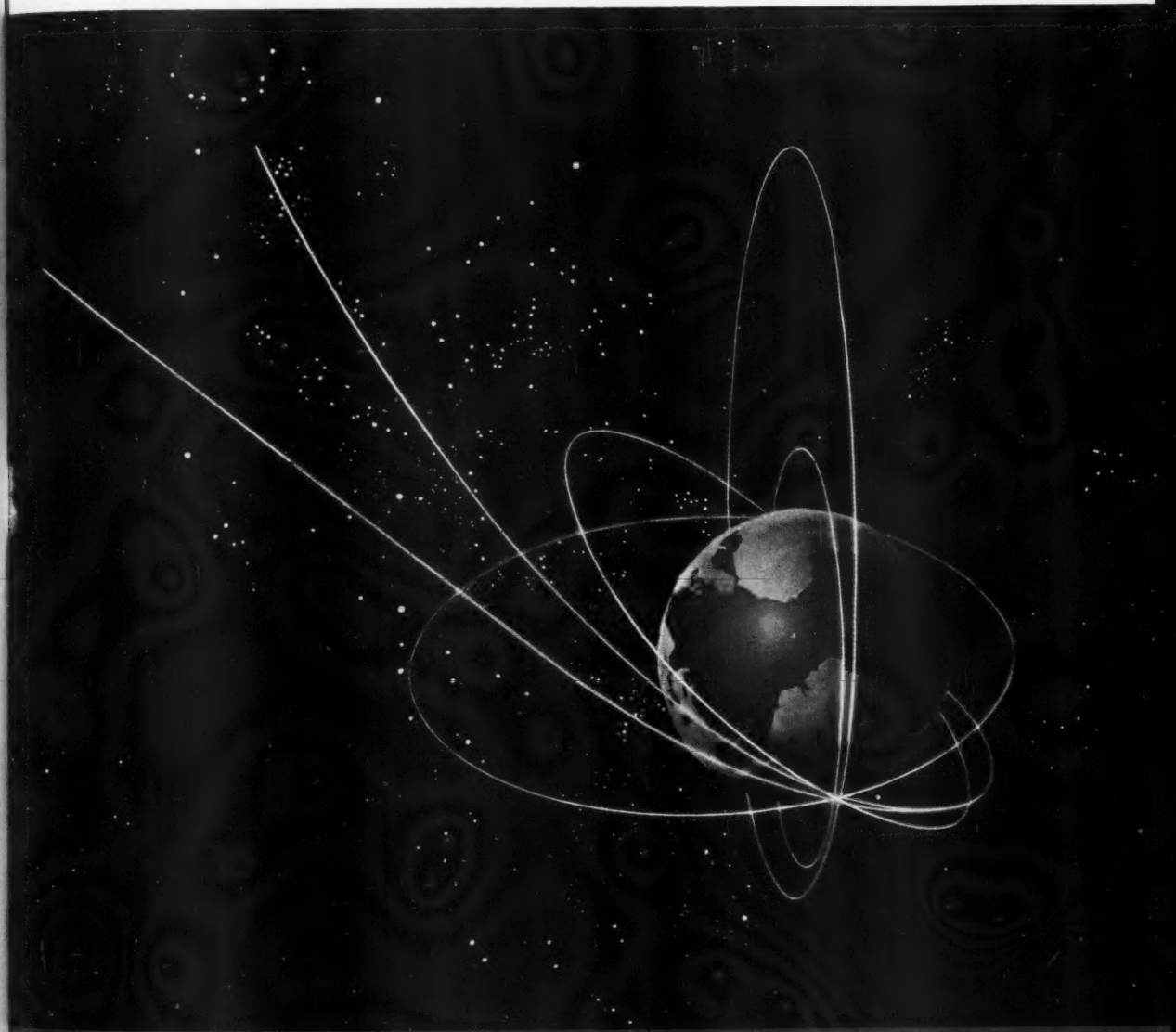
AERO/SPACE ENGINEERING

VIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT



A special issue

ENGINEERING FOR SPACE FLIGHT

APRIL | 1959

Louis G. Dunn ● Richard H. Parvin ● Hollingsworth Franklin Gregory ● H. Guyford Stever
Clayton C. Clark, Jr. ● Harry Esses ● Louis N. Ridenour and Bruno W. Augenstein ● Jack N. Nielsen
Robert H. Boden ● James D. Welterlen ● Edgar Schmued ● Hugo F. Mohrlock and Earl A. Kops

STEPS IN THE RACE TO OUTER SPACE

Lunar Unicycle

This 30-foot high Unicycle is designed for preliminary exploration of the Moon, once a base camp has been established. It's entirely constructed of inflated, rubberized fabric, with the exception of strengthening members, hatches and a few other items of equipment. Gyros stabilize and steer the vehicle; electric motors furnish the driving power.

Electricity for the motors and instrumentation comes from solar batteries mounted in the "parasol". The cleated, rotating wheel upon which the Unicycle travels is made of inflated tubes. A spare wheel, carried around the body, acts as a bumper in traversing narrow defiles. Built in two sections, these wheels are assembled by belt-lacing type fasteners.

The upper level, the navigating and communications deck, is ringed with recording and surveying instruments. Living quarters make up a middle deck and below is the hold with supplies, spacesuits, oxygen equipment and spare apparatus, needed for survival.

In the background, two of the expedition's ferry ships are seen; one landing, one unloading in the bright Earthlight.

Inertial navigation systems will play an increasing role in the exploration of outer space. ***ARMA***, now providing such systems for the Air Force ATLAS and TITAN ICBM's, will be in the vanguard of the race to outer space. ***ARMA*** ... Garden City, New York. A Division of American Bosch Arma Corporation.

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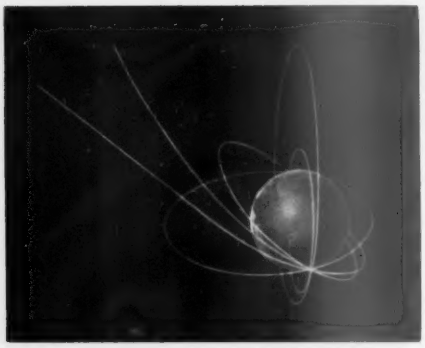

Earth From Near the Moon

An original rendering in watercolor by Fred Wolff, of Wright Aeronautical Division, Curtiss-Wright Corp., rates high as one of the most striking illustrations ever to dress an Aero/Space Engineering cover. Mr. Wolff, one of the nation's foremost astronautical illustrators, reports his effort was to portray the theme of this, our Space Flight Issue. We think readers will agree he has done so with this space flight view of our planet (with artificial satellite orbits and spatial probes made visible by artistic license) and has produced a beautiful work of art. The moon is source of the light shown reflected by the Atlantic Ocean.

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AERO/SPACE ENGINEERING

VOLUME 18 / NUMBER 4 April 1959

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Original R. T. Handville painting shows Sparrow III being delivered by McDonnell F4H-1.

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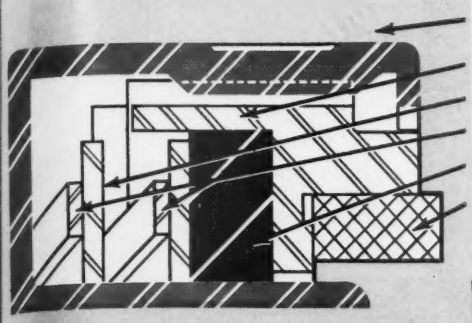

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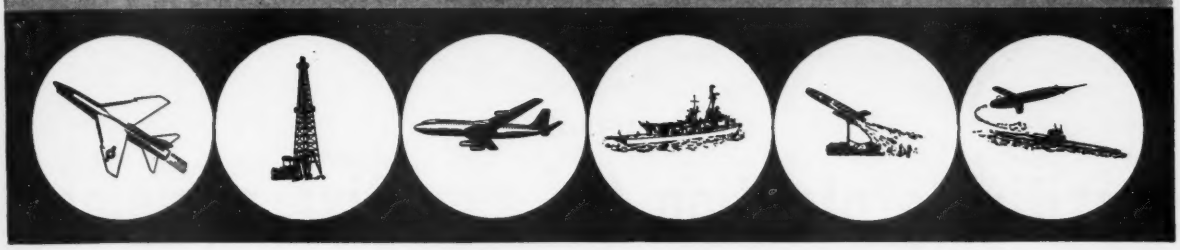

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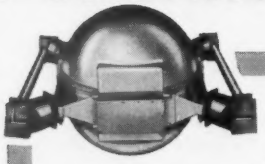

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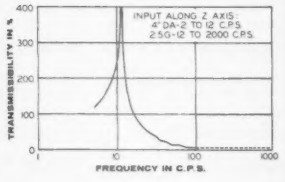

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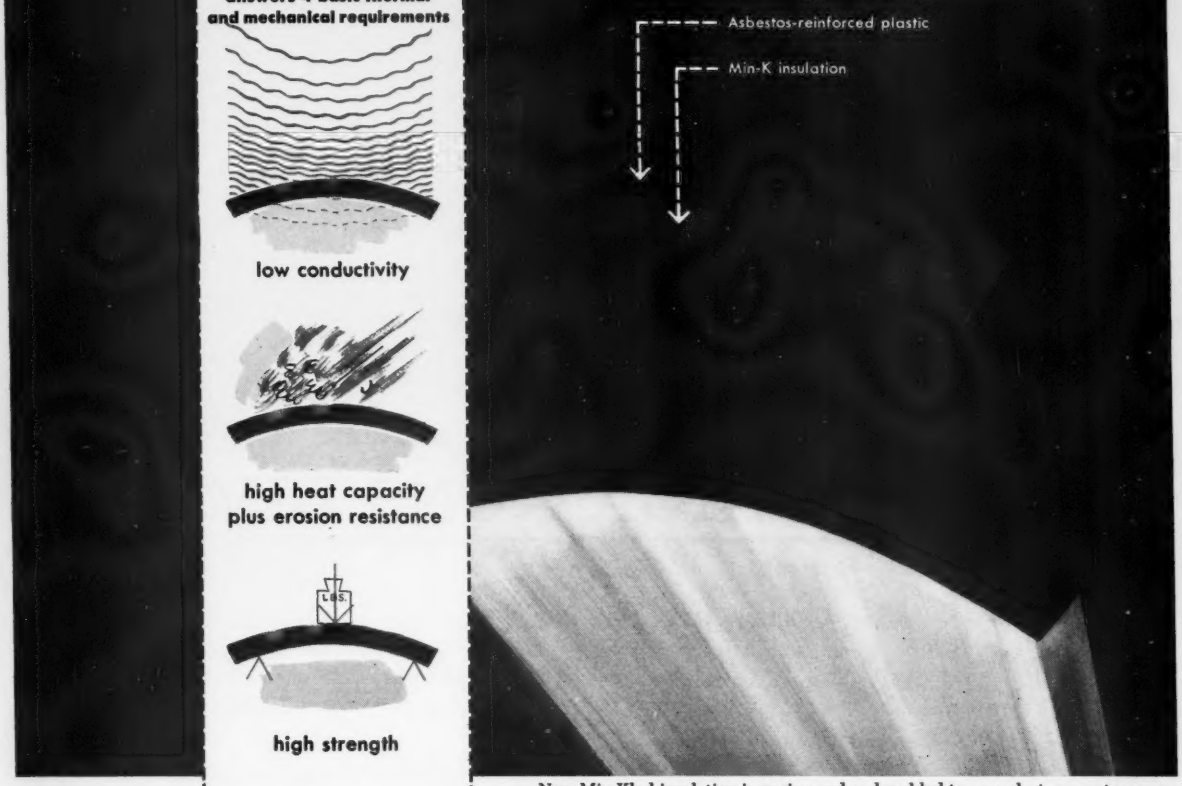

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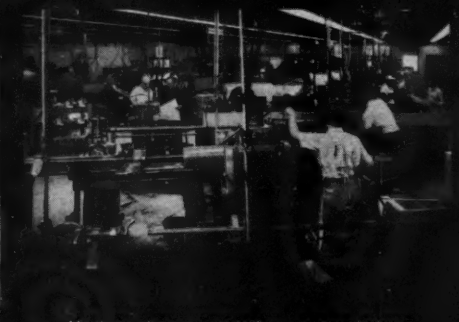

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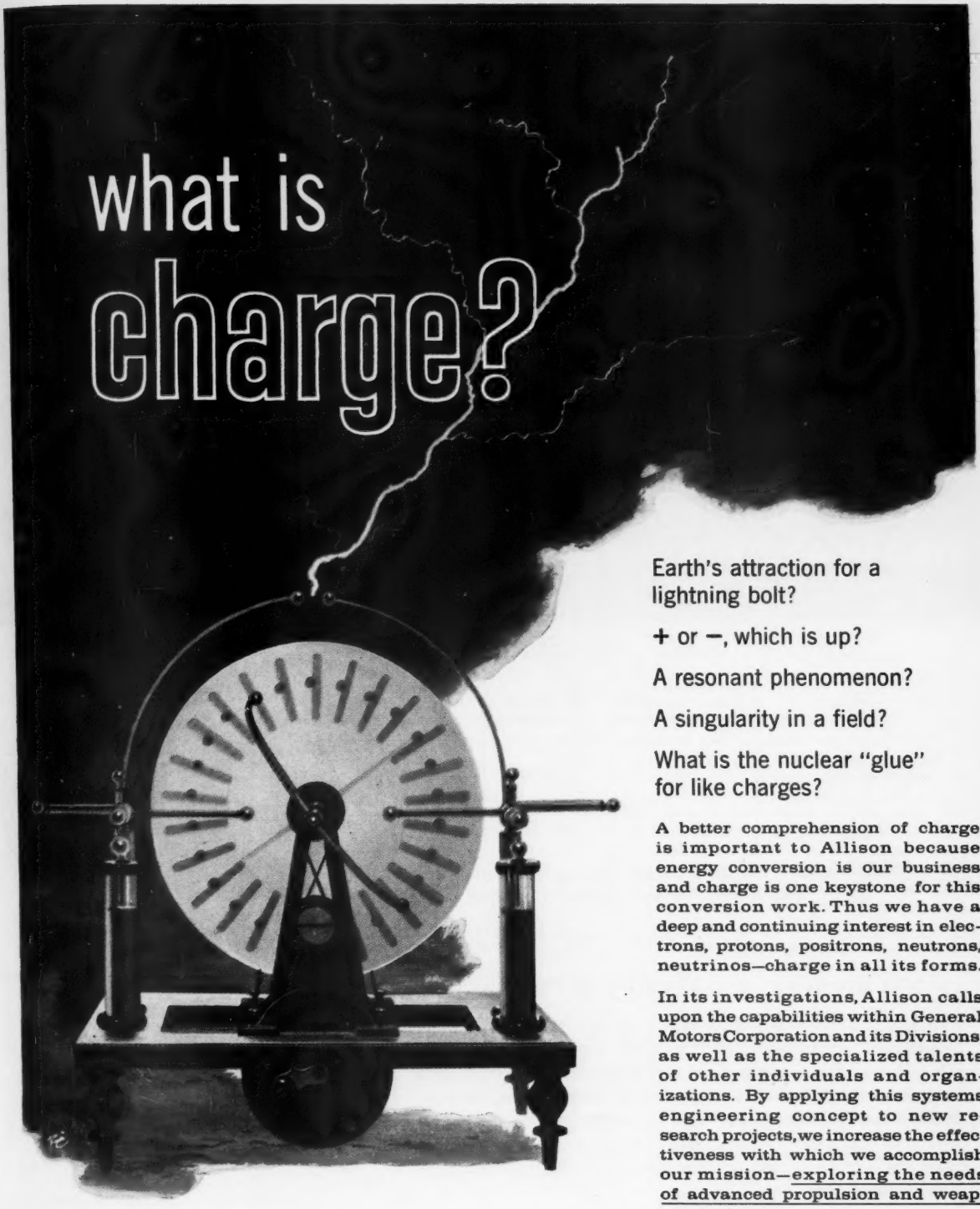

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+ or −, which is up?

A resonant phenomenon?

A singularity in a field?

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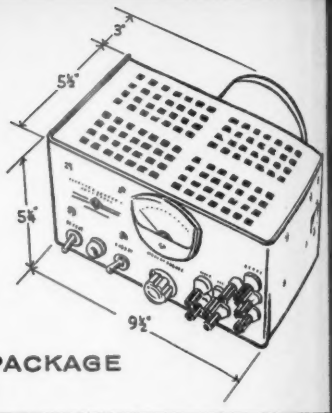
−150v, dc	0.5v	2 ma	±1v



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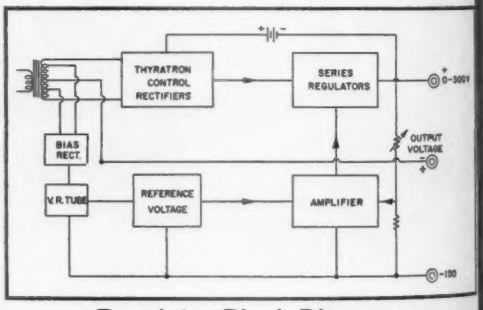
...ALL FROM A COMPACT PACKAGE

120 Watts In 0.2 Cubic-Foot Package...

Excellent performance is obtained by using two regulator circuits. A high-efficiency controlled rectifier maintains the optimum operating voltage for a series regulator, regardless of line-voltage changes, load changes, or changes in output voltage setting. Wide-band regulator circuits and high-frequency by-passing of the output make for low output impedance over a wide frequency range. A large capacity fan provides cooling without dependence on convection, permitting the stacking of any number of units.



Regulator Block Diagram

Type 1205-B Adjustable Regulated Power Supply, $290

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XUM

IAS News Notes

April 1959

MANY AREAS OF TECHNICAL AND GENERAL INTEREST to IAS members in air and space flight will be covered at the Institute's four-day National Summer Meeting in Los Angeles, June 16-19. Seventeen technical sessions have been scheduled, six of which are classified and cosponsored by the Air Force, ARDC Office in Los Angeles. James H. Douglas (pictured at right), Secretary of the Air Force, will be guest speaker at the meeting banquet at the Ambassador Hotel on the evening of the 18th. IAS President William Littlewood will be toastmaster. Luncheon speakers will include Rear Adm. J. Monroe, USN, Cmdr., Pacific Missile Range; Vice Adm. W. G. Cooper, Commander, Antisubmarine Defense Force, U. S. Atlantic Fleet; and Peter G. Masefield, Managing Director, Bristol Aircraft Ltd.

THE TRAINING CENTER FOR EXPERIMENTAL AERODYNAMICS, Rhode-Saint-Genese, Belgium, is receiving applications for entry from qualified graduate engineers and scientists for the one-year diploma course in Experimental Aerodynamics for the academic year beginning on October 12 and ending July 9, 1960. The Center, founded in 1956 as an international institution, has a well-equipped range of modern wind tunnels in its laboratories near Brussels. There are no fees. A number of student fellowships have been established to cover living expenses. Applicants should airmail requests for application forms which should be returned by the 18th of this month to: "The Director, Training Center for Experimental Aerodynamics, 72, chaussee de Waterloo, Rhode-Saint-Genese, Belgium."

FOR THOSE WHO FEEL THEIR PROFESSIONAL INTERESTS are "earthy" (as compared to technical articles in this special-interest issue of AERO/SPACE ENGINEERING), our pages next month will carry a variety of non-spatial discussions. These include problems in control of manned aircraft, achieving reliability, the current picture of air transport and development, a critical examination of hydro-fatigue testing, and a look into a technique for the study of details in compressible flow -- microschlieren.

STUDENTS AT WORK -- April promises to be the biggest month of the year for embryonic engineers affiliated with 77 IAS Student Branches throughout the nation. It (and the beginning of May) is the month of technical paper competitions with seven Regional Student Conferences scheduled as follows: April 4 - Northeastern, Cornell University; April 9-10 - Southeastern, Atlanta, Ga.; April 16-18 - Southwestern, Fort Worth, Texas; April 23-24 - St. Louis, St. Louis, Mo.; April 30-May 1 - West Coast, IAS Building, Los Angeles; May 1-2 - Middle Atlantic, Catholic Univ., Washington, D. C., May 5 - Detroit, University of Detroit.

INTERNATIONAL, NATIONAL, & JOINT MEETINGS CALENDAR

Apr. 5-10	1959 Nuclear Congress, Municipal Auditorium, Cleveland.
May 25-27	National Telemetering Conference, Cosmopolitan Hotel, Denver. Sponsored by IAS, ARS, ISA, and AIEE.
June 11-13	1959 Heat Transfer and Fluid Mechanics Institute, University of California, Los Angeles. Cosponsored by IAS.
June 16-19	IAS National Summer Meeting, Los Angeles.
Sept. 9-11	Midwestern Conference on Fluid and Solid Mechanics, University of Texas, Austin. Cosponsored by IAS, AFOSR, ONR, NSF, and eleven technical societies.
Oct. 5-16	Seventh Anglo-American Aeronautical Conference, New York.
Nov. 2-4	IAS National Midwestern Meeting on "New Frontiers in Aviation," Lassen Hotel, Wichita, Kansas.
Nov. 18-19	National Air Transportation Meeting, San Francisco.

SECTION MEETINGS CALENDAR

Apr. 1	Philadelphia: Dinner Meeting and Tour of Naval Air Turbine Test Center, Trenton, N. J. (Social hour 6:30, dinner 7:30, tour 8:30 p.m.)
Apr. 1	Tullahoma: Technical Meeting, AEDC Conference Room, 8 p.m., "Aerothermodynamic Test Data: How Is It Used?" by A. Lengyel, G.E. Missile & Space Vehicle Dept.
Apr. 11	Niagara Frontier: Social Meeting - Spring Dance, Buffalo Yacht Club, 10 p.m.
Apr. 14	Baltimore: Joint Dinner Meeting with Washington and Hagerstown Sections (Social hour 6:30, dinner 7, meeting 8 p.m.), Occidental Restaurant, Washington. "Nuclear Power for Aeronautics and Astronautics" by Col. J. A. Armstrong, Aircraft Nuclear Propulsion Office and Col. W. A. Tesch, Chief of Airc. Proj. Branch.
Apr. 14	Los Angeles: Classified Specialist Meeting, IAS Building, 8 p.m. "Thermo-Structural Design for High Temperature Flight" by Drs. Henry T. Ponsford and Robert M. Wood.
Apr. 14	San Antonio: Dinner Meeting, Lackland AFB Officers Club, 6:30 p.m. "Education of the Air Force Officer for the Space Age" by Col. B. P. Blasingame, U. S. Air Force Academy.
Apr. 15	Chicago: Joint Meeting with Mechanics Colloquium, Illinois Institute of Technology (Dinner 5:30, meeting 6:30). "Electric Conductivity, Heat Flow and Diffusion in an Ionized Gas" by Prof. J. M. Burgers, University of Maryland.
Apr. 16	Los Angeles: Dinner Meeting (Social hour 6, dinner 7, meeting 8 p.m.), IAS Building. "Physical Characteristics of Planetary Systems" by George Gamow.
Apr. 16	Texas: Specialist Meeting on Aeroelasticity, Children's Museum, Ft. Worth, 8 p.m.
Apr. 22	South Florida: Dinner Meeting, 7 p.m "Jet Power" by William Littlewood, Vice President, American Airlines, and President, IAS.

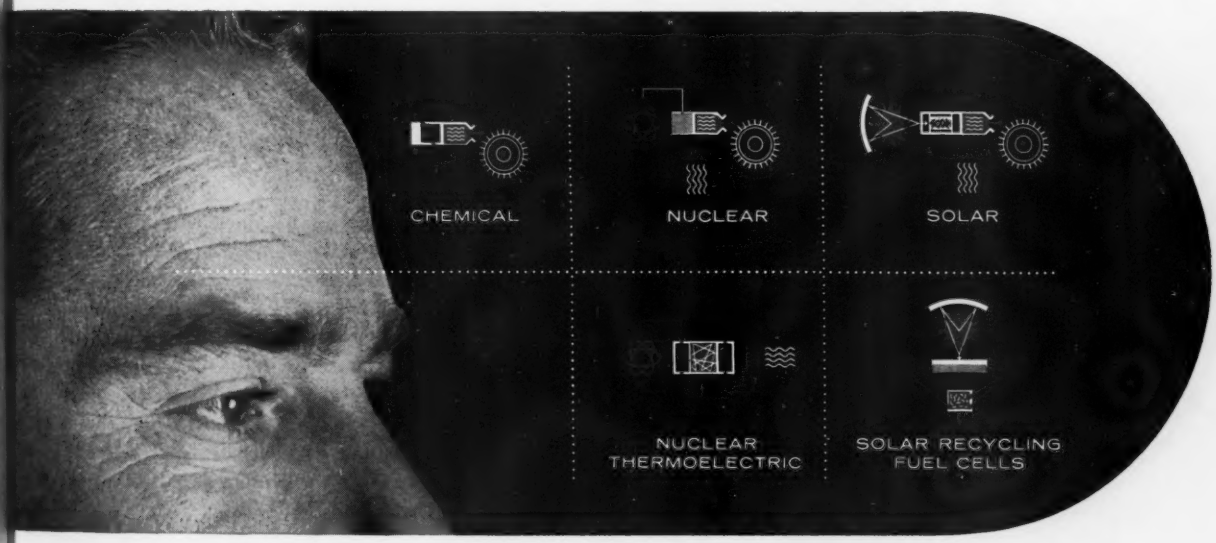
XUM

What Sundstrand Turbo is doing in advanced power systems for space vehicles

Sundstrand Turbo engineers are deep in the study of advanced power systems for interstellar space travel, with thinking that is years ahead of current missile planning and requirements. The five systems shown here that have been developed or are currently being developed, include: (1) Open and closed cycle chemically-fueled power systems, (2) Nuclear power systems, closed cycle, (3) Solar power systems, closed cycle, (4) Thermionic and thermoelectric power systems, and (5) Solar photo-voltaic and solar recycling fuel cell power systems. The suitability of a particular power system depends on factors such as the power to weight ratio, the flight duration and environmental conditions, the overall reliability, the effect of a malfunction on the society living within the regime of the device, the availability of the system, and, of course, the ultimate cost.

The important fact is that power ranging from one to hundreds of kilowatts for periods from a few days to years will be required in space vehicles of the future. Sundstrand Turbo's achievements in the design, development and production of chemically-fueled power systems provide us with a broad base of experience for extending the present state-of-the-art with minimum development effort.

If your requirements lie in the area of advanced power systems for long duration space vehicles, you might benefit from the optimization studies, development capabilities and precision production facilities offered by the Sundstrand Turbo team. *Write for informative brochure–"Sundstrand Turbo Facilities and Capabilities."*



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A division of
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THE BETTMANN ARCHIVE

Forging "new metals" has been routine procedure at Wyman-Gordon for 75 years. Contrasting the modern marvels of metallurgical development is the oldest metal employed by man—copper. Here you see the largest copper closed die forging ever produced—a Re-entry Shield weighing 1875 pounds (67-1/2" x 21-1/2"). Unexcelled know-how, with the availability of the most modern forging equipment, assures the ultimate in forging quality to meet the constantly expanding demands of progress—man's quest for greater speeds and power in his unending exploration farther and farther into yesterday's unknown.

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IAS News

. . . a record of people and events of interest to Institute Members

West Coast Library Offers Special Indexing Service

A special service for aero/space scientists and engineers is offered on the West Coast by the Pacific Aeronautical Library through its Uniterm Index of periodical literature in the field.

As periodicals are received, articles of interest are indexed according to a "unit term" and corresponding number. The index is available every 3 days; in addition, a posting list of these "uniterms," or headings, in alphabetical and numerical order, is issued every 3 weeks. Three quarterly-cumulated volumes and an annual volume—all in book form—also are available.

Bound volumes include the uniterms in alphabetical order, with accession numbers of the indexed articles, an alphabetical list of authors, and a list of accession numbers and complete citations for corresponding articles.

The service is available in part or in its entirety; the cost of the annual volume alone is $25.

Inquiries may be addressed to the Library at 7660 Beverly Blvd., Los Angeles 36, Calif.

New Corporate Member

Radio Corp. of America Defense Electronic Products has become a Corporate Member of the Institute.

RCA is engaged in research, development, and production of electronics equipment for military and civil, ground and airborne applications in aeronautics. An Advanced Military Systems Department is maintained which has system engineering responsibility for aeronautical projects.

Areas of activity include the Ballistic Missile Early Warning System, the furnishing of specific items, such as missile checkout and launch equipment for the Atlas, and instrumentation, search, and tracking radars. Airborne and ground weather radars, Loran, and an air traffic control transponder beacon are among RCA's commercial items.

RCA has an equipment maintenance and support organization, as well as a service organization devoted to installation, servicing, and training of personnel. One of the tasks performed is the supplying of services for the Missile Test Project at Cape Canaveral.

Two IAS Associates Organize Own Firm

John A. Dickie (A) and Karl Unholtz (A) have announced formation of the Unholtz-Dickie Corp. in Hamden, Conn. Mr. Dickie will serve as President, and Mr. Unholtz will be Vice-President and Chief Engineering Officer.

The new firm will provide professional engineering services on an advisory, training, or task basis, covering the full scope of vibration problems, including fatigue, shock and shake testing, designed to withstand dynamic loads, suspension systems, noise control, and equipment and controls associated with dynamic testing.

Both founders were formerly associated with MB Manufacturing Co.

Eight IAS Members Named to Lead Republic Society

With a predominately Institute of the Aeronautical Sciences membership, the Republic Aviation Society of Engineers and Scientists (RASES) has been founded at Republic Aviation Corporation's Long Island plant. The RASES roster includes about 200 names, most of whom are in the Structures Division. A Systems Division is also being organized. The primary requirement for membership in the new group is affiliation with a national society in the aero/space field.

RASES officers are President Irving Singer, Vice-President Norman Grossman, Program Chairman Arthur Bertapelli, Secretary D'Amaso Garcia, Membership Chairman Herman Axelrod, Finance Chairman Milton Cohen, Publications and Publicity Chairman E. A. Simkovich, and Structures Division Chairman Raul (cq) Benedictor. Dr. Grossman is an IAS Associate Fellow; all others are IAS Members.

The new group reports that its primary purposes will be to aid and encourage the professional and technical growth of engineers and scientists at Republic. Secondarily, it hopes to stimulate interest in the technology of the aeronautical and astronautical fields for technical personnel employed in the Long Island area. Two functions of this latter aim will be encouraging members to participate actively in programs of recognized national engineering and scientific societies and providing supplementary local activities adding to the programs of national groups.

The Structures Division held its first meeting in Farmingdale, L.I., on November 12. Fifty members and guests heard a lecture on "Effects of Dynamic Loading" by Aaron Finnerman, Republic's Assistant Chief of Computing Engineering.

The second meeting, attended by 55 persons, was held in Huntington, L.I., on December 10. George Gerard (AF), Assistant Director of Research at New York University, spoke on "Elevated Temperatures and Structures," presenting a summary of theoretical and experimental investigations on buckling, creep buckling, and photothermal-elasticity.

At the February 10 meeting, an audience of 160 heard Samuel Batdorf, of ARPA, Department of Defense, speak on "Propulsion Aspects of Space Flight."

At First RASES Meeting—Officers and members of Republic Aviation Corporation's new Society of Engineers and Scientists listen to opening remarks by Paul Baker (F), standing. Seated, *left to right*, are Norman Grossman (F); Aaron Finnerman, who lectured on "Effects of Dynamic Loading"; Arthur Bertapelli (M); Irving Singer (M); and Herman Axelrod (M).

VERTICAL FLIGHT

VERTICAL FLIGHT Rotary or fixed wing. In either type of VTOL aircraft, control systems must provide precise and positive transfer of motion under all operating conditions. Regardless of size, a Shafer Aircraft Bearing will deliver greater load-carrying capacity and service life for its envelope dimensions and weight than any other self-aligning antifriction bearing available.

Shafer engineers have more experience with design requirements of successful vertical flight control systems than any other group in the industry. Consulted early in design stages, they can save valuable space and weight with Shafer Self-Aligning Aircraft Bearings.

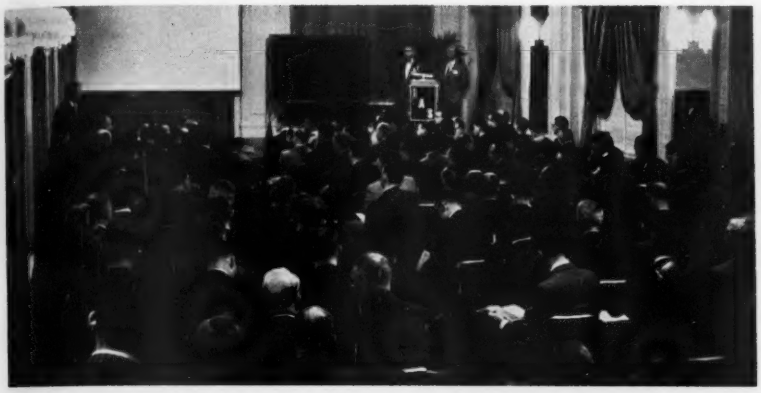
Whatever your requirements for aircraft bearing performance, call on Shafer's specialized design experience. Shafer Bearing Division, CHAIN Belt Company, 801 Burlington Avenue, Downers Grove, Illinois

SHAFER DIVISION OF CHAIN BELT COMPANY

Record 2,603 Register at IAS 27th Annual Meeting

First A/SE Symposium on Aero/Space Industry Advertising Held

Another Is Being Planned



WHILE a full pictorial report of the Institute's 27th Annual Meeting, January 26–29, could fill an album, these three photos depict one of the many well-attended technical sessions (*top*) and a "first" at the meeting—the Symposium on Aero/Space Industry Advertising, shown in the two lower photos. At left is the Propulsion I Session in progress in the East Ballroom on January 26. Session Chairman Eugene Manganiello, Assistant Director, Lewis Research Center, NASA, and Earl R. Hinz, Design Specialist, of Convair Astronautics, are on the platform. Mr. Hinz's paper was on "What Is Specific Impulse Worth?" Meeting registration was 2,603—a record.

AERO/SPACE ENGINEERING's Symposium on Aero/Space Industry Advertising, pictured here in two views, was held on January 26 simultaneously with Annual Meeting sessions. An estimated 70 company advertising executives and ad agency personnel were present. A section of the audience is pictured in the bottom photo during the question-answer period. Purpose of the Symposium was to create a better understanding of all factors necessary to the development of sound, effective advertising programs of maximum benefit to both advertiser and aero/space engineers. On the basis of comments immediately after the event and since, plans are progressing to hold similar symposiums in other sections of the nation. (See letter on page 29.) *Proceedings* of the Symposium are being planned and will be announced in this magazine when available. The Symposium panel is hard at work in the center photo. *Left to right* are pictured W. A. Shrader, IAS Director of Publications, who was moderator; C. T. Foss, Vice-President, American Bosch Arma Corp.; Edward Ledeen, Staff, Engineering Operations, Wright Aeronautical Division, Curtiss-Wright Corp.; S. Holt McAloney, Public Relations Director, Ford Instrument Company, Division of Sperry Rand Corp.; L. Eugene Root, Vice-President and General Manager, Missiles and Space Division, Lockheed Aircraft Corp.; Ernest G. Stout, Assistant Resident Manager (Washington, D.C.), The Ralph M. Parsons Co.; and Charles Tilgner, Jr., Chief Aeronautical Engineer, Grumman Aircraft Engineering Corp.

Of possible interest to our Engineer readers active in 35-mm. photography are the technical data behind these A/SE photos. All were shot in available light at 1/10 sec. on Tri-X film with an Argus C-4, hand-held. Aperture was f2.8.

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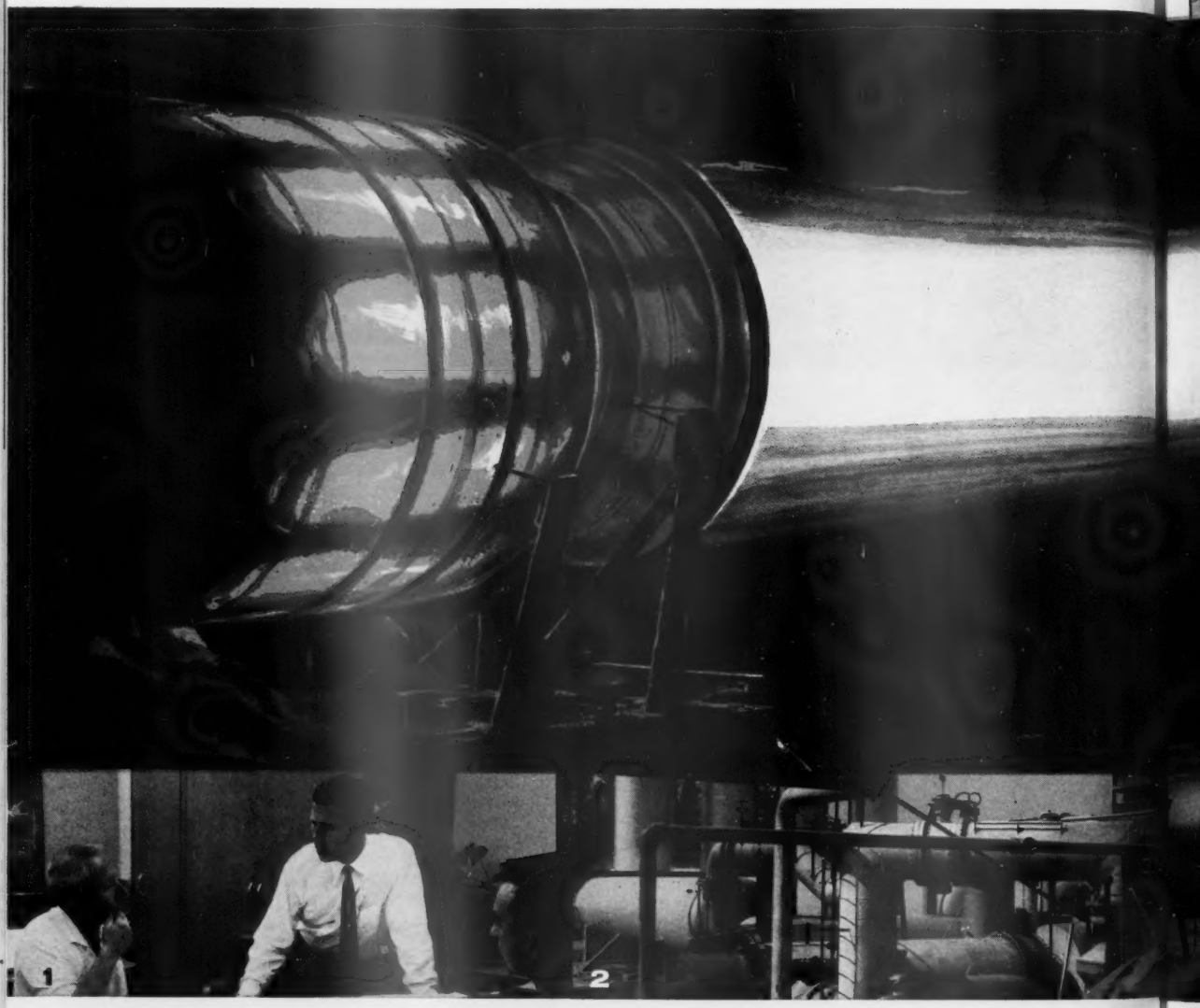
Marquardt

ADVANCED TEST FACILITIES

FOR AIR AND SPACE



Test facilities conceived, designed, developed, and operated by Marquardt Aircraft—which include the USAF-Marquardt Jet Laboratory and test installations of the U. S. Navy—perform an important role in the development of advanced propulsion systems, controls and accessories for air and space operations. Here, in a creative engineering environment, professional engineers specializing in analysis, design, and operation of test equipment are constantly challenged by the complex requirements which must be satisfied to support critical development programs, including test support for long-range space research projects currently underway. Simulation of high altitude engine and equipment operating conditions, handling and testing with new chemical fuels, solving the problems of extreme temperatures and vibration, extrapolation of data for space applications, and recording test data under conditions never before simulated, are only a few of the research and development areas presently being explored by engineers in Marquardt's Test Division.

Engineers and scientists whose training and experience qualify them for responsible positions in the analysis, design, and operation of such advanced facilities will find full opportunity to demonstrate their talents at Marquardt. May I suggest you contact Mr. Floyd E. Hargiss, Manager of the Professional Personnel Department, 16547 Saticoy Street, Van Nuys, California.

Roy E. Marquardt, *President*

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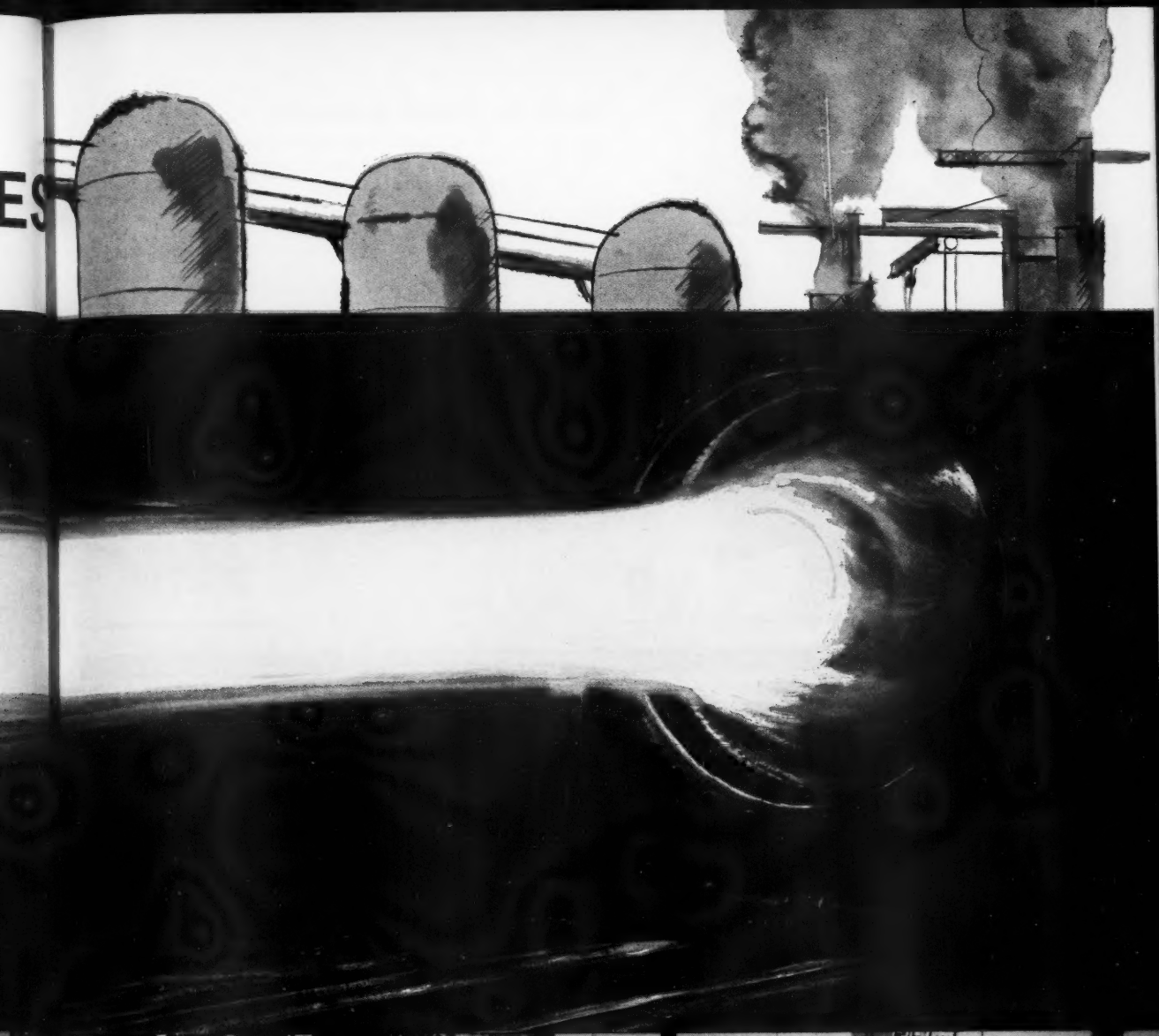

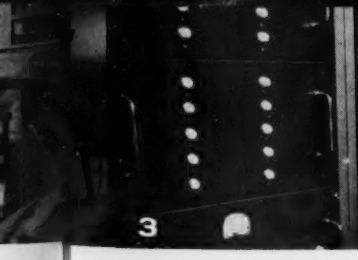

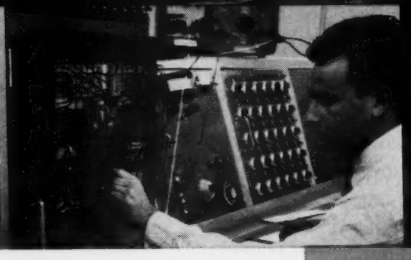

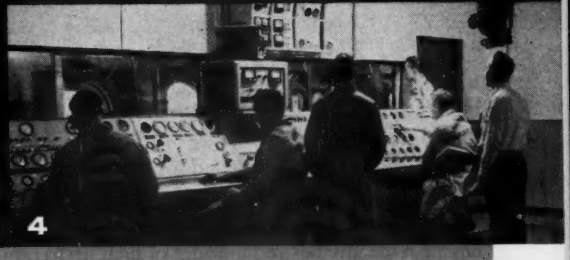

1—Test Division engineers under Chief Engineer Leigh Dunn (center) pioneer advanced development programs in Marquardt's unique and modern test facilities. Professional engineers wishing to join this creative engineering environment will find opportunities in many fields, including:

2—Facility Design—Engineers experienced in design, mechanical and thermodynamic analysis of industrial processes including systems for large air flow, steam, fuels, propellants, and oxidizers for both cryogenic and extreme temperatures.

3—Instrumentation—Engineers to advance the design of high-speed recording systems and analog computers and to use these systems in the collection of test data.

4—Facility Operations—Engineers to coordinate and supervise the setup and operation of test programs for supersonic jet engines, engine controls, and rotating accessories.

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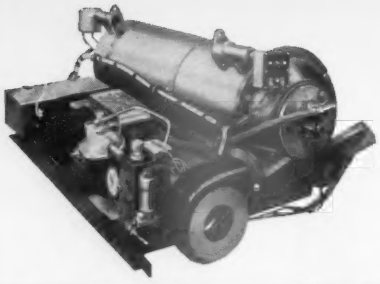
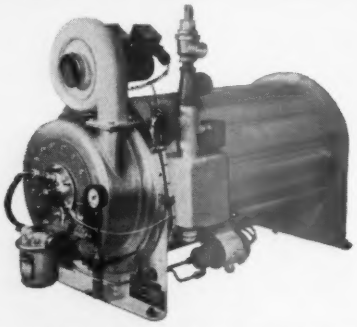


90,000 Btu/hr Janitrol liquid heater

for support vehicle comfort and cargo heating, windshield defrosting. Ideal for use on fire trucks, movers, weapons loaders, personnel carriers, in temperatures to −65° F.



500,000 Btu/hr Janitrol liquid heater

for portable structures, large vehicles, and for heating decontaminents and cleaning fluids on mobile ice removal units.

1,000,000 Btu/hr Janitrol liquid heater

for missile fuel transfer operations, large portable structures, airlifted equipment. Approximately 18″ in diameter, 47″ high, weight: 260 lbs.

reliable ground support liquid heat packages

Missile and aircraft support equipment builders use Janitrol *liquid* heater packages with little or no modification because they're designed for military applications. Meeting appropriate MIL specifications and fully qualified, they're available in outputs to 1 million Btu/hr. They provide any desired amount of heat up to rated output and automatically maintain constant temperatures.

As an example of acceptance, most Air Force crash-fire vehicles are equipped with one or more of these heaters, for engine, chemicals, cargo and crew space heating. Multi-fuel operation is standard, and they perform reliably in multiples for heat requirements which exceed the output of a single unit.

Ask your Janitrol engineering representative for a proposal for thoroughly proven ground support heating equipment.

Janitrol Aircraft Division, Surface Combustion Corporation, Columbus 4, Ohio.

JANITROL

pneumatic controls • duct couplings & supports • heat exchangers
combustion equipment for aircraft, missiles, ground support

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Proceedings of ICAS Published in London

Proceedings of the First International Congress in the Aeronautical Sciences, held in Madrid, Spain, last September, have been published in two volumes as *Advances in Aeronautical Science*, according to the publishers, Pergamon Press, 4 and 5 Fitzroy Square, London, W.I., England.

Editors of the 1,200-page work, containing 568 illustrations and all 46 papers presented during the Congress by the world's leaders in the aero/space sciences, include Robert R. Dexter, Secretary of the Institute of the Aeronautical Sciences. Others are Theodore von Kármán, A. M. Ballantyne, H. Blenk, Maurice Roy, and Hugh L. Dryden.

Advances in Aeronautical Sciences, according to the publishers, is available on 14 days' approval from reputable booksellers without obligation, or by writing directly to: Sales Director, Pergamon Press, Inc., 122 E. 55 St., New York. The price is $25.

IAS News

Necrology

Halton H. Friend

The Institute has received notice of the death of Halton H. Friend (AF).

At the time of his death Mr. Friend was Assistant to the President, The Arnold Engineering Co., in Marengo, Ill. In his long career, he had been a senior physicist with the U.S. Navy and had been associated in engineering capacities with RCA, Magnet Alloy Div., Cinaudagraph Corp., Bendix Aviation, and Curtiss-Wright Corp. He was the author of two books—*Magnetic Circuit Calculations* and *Things Deserving Consideration in Magnetic Design*.

Mr. Friend received a B.S. in Physics from Northwestern University in 1926 and an M.S. degree in Physics from Lehigh University in 1929. He was a registered professional engineer in Connecticut, a member of the IRE, and a fellow of the Society of Motion Picture Engineers.

Jack Frye

Jack Frye (F), one of the founders of Trans World Airlines, was killed in an automobile accident in Tucson, Ariz., on February 4. He was 54 years old.

Mr. Frye was president of the Frye Corporation, manufacturer of the F-1 Safari.

A former head of Trans World Airlines, he helped build TWA from an operation with 600 employes to a $70,000,000 corporation with more than 17,000 employes. Many operating methods and techniques introduced by Mr. Frye at TWA are now standard practices on the world's principal airlines.

A leader in the development of high-altitude all-weather flying equipment, he worked with Donald Douglas to develop the first of the famous DC-series planes. In 1934, when he became president of TWA, Mr. Frye had cut transcontinental flying to 16 hours. His plans contributed to the well-known Constellation and his pioneering had then cut cross-country flying from a 48-hour trip to approximately 10 hours.

In 1947, Mr. Frye left TWA to become president of the General Aniline and Film Corp.

Gysbert C. Snyders

The Institute has just been informed of the death of Gysbert C. Snyders (M) on January 1.

Mr. Snyders was a native of Holland and received his engineering degree from the University of Aachen, Germany, in 1939.

At the time of his death, Mr. Snyders was president of Aeronautical Consulting Engineers, Hague, Holland. He was president of Avio-Diepen Co. from 1948 to 1955, and served as an aeronautical engineer to the Royal Netherlands Naval Air Service before and during World War II.

Capt. Robert E. Williams

The Institute has just learned of the death of Capt. Robert E. Williams, USAF (M), on December 24, 1958.

Capt. Williams was an Experimental Flight Test Officer at the Air Force Flight Test Center at Edwards AFB. Before joining the Air Force, he had been a Development Engineer with AiResearch Manufacturing Co. in California.

Capt. Williams received a Bachelor of Engineering degree from the University of Southern California in 1949.

News of Members

Arthur P. Adamson (M), former Manager of the Flight Propulsion Laboratory Department's Engine Development Operation, Aircraft Gas Turbine Division, General Electric Co., has been named Manager of its Vertical Takeoff and Landing Engine Development Project.

Cecil W. Barnes (M), IAS San Antonio Section Chairman, has assumed the post of Deputy Director of Special Weapons, San Antonio Air Materiel Area, an AMC activity, at Kelly Air Force Base. He was formerly Chief, Weapons Systems Division, Plans and Programming Office.

Edward S. Carter, Jr. (A), formerly Assistant Chief of the Dynamics Branch, has been promoted to Assistant to the Chief Engineer, Sikorsky Aircraft, Division of United Aircraft Corp.

Brig. Gen. Marcus F. Cooper (AF), formerly Commanding Officer, Air Force Test Center, ARDC, Edwards Air Force Base, has been appointed Assistant Administrator, FAA Office of Plans and Requirements.

Ernest A. Eichelbrenner (M), formerly with ONERA, has been named an Associate Professor at the University of Poitiers, France.

C. Towner French (A), has become associated with General Precision Laboratory Inc., Pleasantville, N.Y., a subsidiary of General Precision Equipment Corp., as Manager, Military Liaison—Industrial Products Division. He formerly was with Fairchild Camera & Instrument Corp. as General Manager, Industrial Camera Division.

Leroy H. Grumman (HF), Chairman of the Board, Grumman Aircraft Engineering Corp., received the 19th annual Frank W. Hawks Memorial Award from the American Legion Air Service Post 501. Mr. Grumman was honored with the Award for his many contributions to aviation throughout the years.

Robert E. Hage (AF) has become associated with McDonnell Aircraft Corp. as Vice-President and General Manager, Transport Division. He formerly was Project Engineer, Boeing Airplane Co.

James A. Hootman (AF), formerly Staff Assistant, NASA, has been appointed Secretary of the new NASA Inventions and Contributions Board.

Ephraim M. Howard (AF) has been promoted to Department Head, Systems Integration, Minuteman Engineering Division, at Aerojet-General Corporation's solid rocket plant. He was formerly a Technical Specialist on special assignment to the Manager of Applied Mechanics and Systems Division, and headed Fluid Mechanics and Heat Transfer in the Aerophysics Department.

Lyman C. Josephs III (AF), formerly Project Engineer for the F8U-1 Crusader, has been promoted to the position of Chief Engineer—Aircraft, Chance Vought Aircraft, Inc.

Major Patrick W. Powers, USA (M), has been assigned as Special Projects Officer in the Technical Liaison Office, Office of the Chief of Research and Development, Department of the Army.

Bernard L. Prenovich (AF) has become an Associate Member of the Benjamin L. Ortiz Co., Consulting Engineers and Surveyors, Las Vegas, Nev., handling the designing of all types of plant facilities to the aircraft and missile industry.

Charles R. Wood, Jr. (AF), has been appointed Manager, Defense Sales for the Special Products Division of the Weatherhead Aviation and Missile Group, The Weatherhead Co. For the past 3-years he was special Assistant and Technical Advisor to the Commanding General, U.S. Army Transportation Supply and Maintenance Command.

(*IAS News*
Continued on page 135)

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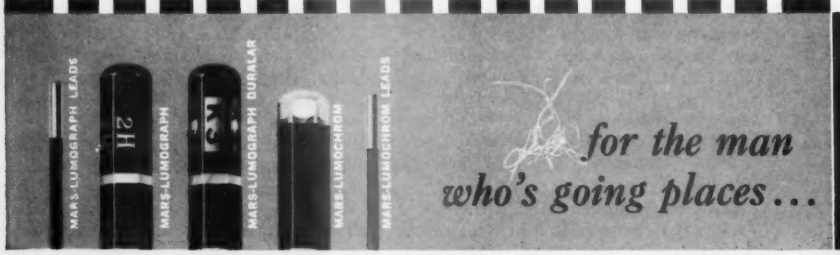

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LETTERS to the Editor

Lauds A/SE Ad Symposium

■ It was a privilege and pleasure to attend AERO/SPACE ENGINEERING's Symposium on Aero/Space Industry Advertising during the IAS Annual Meeting, and I'd like to extend my congratulations to all responsible. I obtained more useful information during its 2-hour duration than I've been able to get in checker-jumping around the country.

All the various industry-related society and association meetings I've attended in the past have been enlightening and informative, but sadly lacking in the advertising "meat" of the type afforded by your Symposium. There should be more of them. People in my profession, especially in this exciting industry, vitally need this information, and it is my sincere hope that your session has established a precedent that will be followed where possible at future meetings. Please accept, also, my sincere thanks for including me on your invitation list.

I'd also like to take advantage of this opportunity to say that I enjoyed meeting many on the IAS staff, and to compliment the Institute on the excellent organization and sound technical content of its 27th Annual Meeting.

Robert B. Hitchcock
Mgr., Publication & Advertising
Janitrol Aircraft Div.
Surface Combustion Corp.

Planning has already begun for more of these meetings. Photos of the first appear on p. 23 of this issue of A/SE.—ED.

Offers Field Trips Plan

■ About a third of the IAS Sections are in aeronautical centers where, because of a concentration of research, development, and manufacturing facilities, plus some very appropriate military activities, there exists an almost endless possibility for scheduling interesting Saturday field trips. However, the other two thirds of the Sections are not quite so ideally situated, so that geographically accessible points of interest are not readily available for a continuing program of trip planning. After several visits, the local aeronautical activities have been covered. Further scheduling must then embrace some basic industries and local operations within the community—interesting enough, but not directly identified with the advancement of the aeronautical sciences. In fact, in my area, a well-established brewery has somehow been construed as a point of interest for aeronautical scientists.

At this time I should like to use this column to make a proposal to other Section Chairmen and to the national officers of the IAS for a cooperative effort in improving the field trip type of activity by extending the area of consideration to the facilities in other communities, wherein airplane travel becomes a part of the field trip program. As an illustration, suppose that a group of IAS members of the Kansas City Section would like to visit the McDonnell Aircraft Corp. facilities in St. Louis. Concurrently suppose that a group of St. Louis Section members would like to visit the TWA Overhaul Base at Kansas City. Here are two good field trip possibilities. Transportation by chartered airplane could be scheduled as follows: The K.C. group leaves for St. Louis at an early, but reasonable, hour. Upon arrival at St. Louis the plane turnaround is made, taking the St. Louis group to K.C. Upon completion of the program in K.C., the St. Louis group departs for home. The K.C. group boards the plane shortly after it lands in St. Louis and goes home. A group of St. Louis Section members, not making the trip, would serve as hosts and tour guides for the visiting K.C. IAS members, while some K.C. Section members would be hosts to the visiting St. Louisans.

Airplane costs have not been investigated as a part of this proposal. However, the prospect of two round trips with a near 100 per cent load factor should keep the charge to each member pretty low. Furthermore, American, Eastern, TWA, and United are all Corporate Members of the IAS and might be in a position to make field trips of this sort more attractive.

In conclusion, it is urged that the Institute evaluate the merits of this proposal and, if fitting, seek to implement a plan for carrying out the extended radius field trip program.

Frederick H. Roever
Chm., St. Louis Section, IAS

A good idea, plainly put. It is felt this program may be readily workable under the proposal submitted recently for Council study. Any two Sections, however, might try it now; a how-goes-it report would make interesting reading in A/SE.—ED.

Education—Another Approach

■ I am not as conversant with engineering curricula as Mr. Hyman (A/SE, Feb., 1959, p. 5). Being a graduate of the University of Notre Dame, it is logical and natural that I am most familiar with that institution. And since Notre Dame inaugurated instruction in aeronautical engineering in 1935, I assumed that every university and some colleges and technical schools had made this same progress before 1935—or since.

I agree with Mr. Hyman, in principle; things in engineering education are not what they might be. However, my approach to the problem is fundamentally different. I believe that teaching a person *how* to think is preferable to teaching a person any specific course or set of courses. If a person can be taught how to use his inductive and deductive powers, if he can be taught how to attack a problem, how to get an "engineering approximation" for solution in as short a time as possible—then it doesn't make a great difference whether the subject of instruction is IC Engines or the Basic Theory of Plasma Physics. Chances are, when our imaginary student gets his first engineering employment, he will use neither. But he will have to know how to think, or rather, how to reason, in any employment that he might undertake.

A rational approach to improvement of higher education in general—not specifically engineering education—would be threefold:

(1) The years spent in the last 2 years of elementary school and the 4 years of secondary school should be utilized better. Thus, I propose going farther than Mr. Hyman. Certain secondary school courses should be taught during the last 2 years of elementary school—e.g., high school algebra, elementary biology, the service courses (typing and possibly shorthand), etc.; several first-year college courses should be taught in secondary schools, as suggested by Mr. Hyman. Personally, I wasted a large percentage of my final 2 years of elementary school, and, to escape a similar fate in secondary school, I completed the prescribed course of studies plus electives during the 3 years I spent attending high school.

(2) During the final year of secondary school, a serious attempt should be made to counsel students concerning their proposed vocation. All too frequently a young person will choose a career blindly—and then spend years debating the wisdom of his immature choice. Valid, sincere counsel by persons in the various vocations would alleviate or eliminate the attendant uncertainty.

(3) One or 2 scholastic years, of 9 months' duration each, should be spent in apprenticeship in one's chosen vocation *before* entering school at the university level. This would give the young person valuable personal experience on which to base his choice of vocation. It is obvious that a secondary school graduate would not be exposed to the direct rays of a high-powered profession, but at least he could bathe in the reflected light of a professional. It is postulated that this plan would produce more dedicated professionals and fewer distracted laborers.

Finally, but most importantly, elementary, secondary, and university education should teach a person a true sense of moral values. Specifically, education should train the whole man. As an example, education should teach a person to perform 8 hours of useful work each day for 8 hours' compensation—and enjoy it.

James A. Martin
Aero. Res. Engr.

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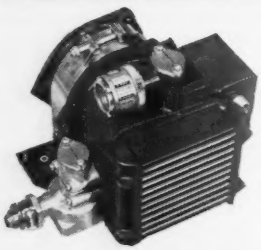

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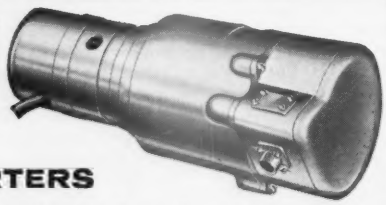

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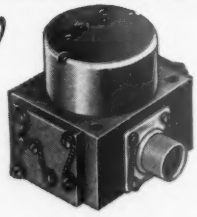

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PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

Mi-1 "Stands on Tail" for Short Landing Run

◆ "Standing an airplane on its tail" has been a figure of speech for years, but it becomes almost a reality with the dead-engine leading technique that has been demonstrated in the Soviet Mi-1 helicopter. According to the *Soviet Aviation* newspaper and the *Wings of the Nation* magazine, the method results in a landing run of no more than 10 m. (about 30 ft.) because of the abrupt flare-out to a nose-up angle as high as 40 deg. to the horizon.

Soviet test pilot V. Vinitskiy, holder of several world records that have been established with the Mi-1 and the Ka-18, developed the procedure. As described in the Soviet periodicals, the technique is as follows:

In case of engine failure, the helicopter is put into a glide at 70–80 km. per hour (about 40 knots). When near the ground, the approach is flared out by an abrupt pitch to a nose-up angle of 25–40 deg. With the rotor inclined at such a large angle to the relative airflow, the horizontal speed is reduced and the landing can be made at a speed not exceeding 10 km. per hour (about 5 knots). Upon completion of the flare-out, "the helicopter tail nods," with ensuing transition to the horizontal position. Then the vertical descent begins, and the pilot gradually increases collective pitch to maintain the rate of descent at 1.5–2 m. (5–6 ft.) per sec. The flare-out should not be accomplished at an altitude of less than 15 m. (about 50 ft.) because the tail rotor will strike the ground and be damaged.

Vinitskiy's method is said to take advantage of the kinetic energy due to the forward speed of the helicopter. This statement, together with the reference to the tail's nodding, indicates that the nose-up pitch of the flare-out is accomplished by means of the trimming stabilizer. As the forward speed is reduced by the flare-out, the trim control loses its ability to hold the tail down and allows it to swing up to the horizontal attitude. If the nose-up attitude were achieved with the differential (cyclic) pitch control, the forward portion of the rotor would be at a high angle of attack, and a further increase in rotor pitch with the collective control probably would stall that portion of the rotor "disc."

The significance of Vinitskiy's method lies in the extreme flare-out angle utilized and the resultant short landing run. In contrast, the previously normal method for such a landing involved a comparatively high landing speed, up to 60 km./hour (about 30 knots), and a relatively long landing run. As deduced in the foregoing paragraph, the difference is due to Vinitskiy's use of the stabilizer trim control, instead of the differential pitch, to accomplish the extreme flare-out. A certain amount of hazard is involved in the method, as indicated by the statement that performance at too low an altitude would damage the tail rotor. On the other hand, a dead-engine landing in any airplane presents its hazards and an unskilled flare-out in a helicopter can cause loss of rotor speed. However, when faced with such an emergency and inadequate landing space, the short landing run of Vinitskiy's technique could well be a lifesaver to any helicopter pilot.

"Compressorless Extrusion" Reported in U.S.S.R. Paper

◆ An interesting item noted recently in a Soviet newspaper referred to so-called "compressorless extrusion" as a process in which the high hydraulic pressures necessary for the extrusion of metal are produced without a compressor of any kind. The newspaper account did not describe the process but made vague reference to spark discharge, oil-filled container, etc. This item instigated speculation that the Soviets may have found ways of generating useful power by means of the discharge of electrical current within a closed hydraulic cylinder; and United States electrical engineers have confirmed that, in the case of large oil-filled power transformers, arc discharge through the fluid could cause momentary high pressures of such magnitude as to burst the transformer shell.

Further evidence of Soviet work along this line appeared in an announcement that the Leningrad Polytechnic Institute has developed a process called "underwater lightning," the discharge of electrical current through fluid under pressure. To quote the release: "Yutkin has succeeded in producing and putting to work a discharge of far greater power than lightning." The article indicates that it has now become possible to bring about a series of momentary pressures of enormous magnitude, something on the order of tens of thousands of kilograms per square centimeter.

Yutkin has reportedly worked out some 150 applications for his process in a wide variety of fields. The Soviet Academy of Sciences has expressed the opinion that his work will find extensive application in modern technology and lead to fundamental changes in machine operations.

In this country, the opinion has been expressed that the Yutkin process, if successful, would have tremendous influence on the metal-working industries, especially in the fields of forging, extrusion, forming, and casting.

Cold Chromating of Parts Reported

◆ The August, 1958, issue of *Soviet Aviation* noted that a new process has been found which eliminates disadvantages encountered in present chromating methods for rebuilding used aircraft parts. The item states that so-called tetrachromate electrolyte, which contains chromic anhydride, sulfuric acid, caustic soda, and sugar and glucose, will permit chromating at room temperature, with low current density, and a build-up rate of 1 micron per min.

It is pointed out that the new process will be much more efficient than the present slow process (which uses only 12 to 13 per cent of the total electrical power for deposition of coating, requires temperatures of 50° to 70°C., and results in plating that is porous and of uneven thickness).

Nuclear Vulcanization Announced by Researchers

◆ Experiments on rubber vulcanization by means of nuclear energy have recently been started in the Soviet Union, according to news from Moscow.

The Moscow Research Institute of the Tire Industry has reportedly used radioactive cobalt for vulcanizing several types of heavy-duty tires. It is stated that, compared with the best rubber produced by ordinary methods, the rubber obtained as a result of exposure to radioactive cobalt has higher thermal resistance, greater resistance to multiple deformations, and is more durable.

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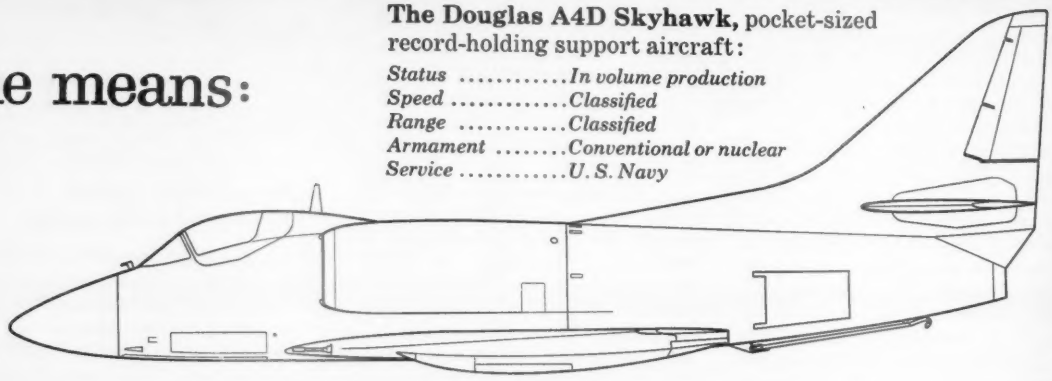

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GUEST EDITORIAL

Some Remarks on the National Space Program

Louis G. Dunn, FIAS
Space Technology Laboratories, Inc.

The necessity for establishing a sound national space program is today one of the problems uppermost in the minds of those individuals in Government charged with the responsibility of the national welfare. The papers appearing in this issue of AERO/SPACE ENGINEERING are a further testimony to the widespread interest in, and the importance being attached to, the technical disciplines associated with space flight. There are, in my opinion, a number of salient facts which will have a profound bearing on how well we as a nation fare in the international space competition. Although these ideas, I am sure, are neither new nor novel, I believe they are worth stating.

We must first take an inventory of the national resources which are immediately available to us and then decide how best to utilize them. The acquired knowledge, the assembled and trained men, the facilities, the associated hardware, and the demonstrated results of the United States ballistic missile program, particularly the Air Force portion which comprises the bulk of the program, must for the coming half decade and perhaps longer continue to be a firm foundation upon which to base follow-on national space commitments.

A review of the many milestones successfully achieved during the past 5 years tells a story of hard work, inventiveness, accomplishment, and single objective. This single objective—the achievement of an operational weapon capability at the earliest possible date—is being realized. Atlas and Thor are but a few months away from becoming operational and ahead of the schedule first prepared.

In addition to this technical and industrial capability, there has emerged from this program a multitude of space "building blocks"—tangible, flyable hardware now on a variety of production lines across the nation which has operated satisfactorily on half-a-hundred flights into space. Aside from the deep space flights, one should note that, throughout the greater part of its trajectory, a ballistic missile travels outside of the earth's sensible atmosphere—i.e., in space.

We in this country have an obligation to this space-enabling capability that has been created. We must utilize it with wisdom. With the wide variety of very real space objectives, we should not divert this capability to trivial or meretricious ventures, nor should we at the behest of interagency competition unnecessarily and uneconomically duplicate significant elements of it. We should continue to develop and expand it, pursuing the weapon system program at its proper and planned priority, and phase in the space usage with a correspondingly planned priority.

Dr. Dunn was elected President of Space Technology Laboratories, Inc., following its separation last year from The Ramo-Wooldridge Corp. (now Thompson Ramo Wooldridge Inc.). He is a former Director of the Jet Propulsion Laboratory, a division of the California Institute of Technology, and holds the Presidential Medal of Merit for his work on torpedoes during World War II, and the Patriotic Civilian Service Award for research and development done by JPL for the Department of the Army. He was elected an IAS Fellow in 1953.

As a second necessary step in our space program, we must continue to develop and expand our present ballistic missile and space technology—that is, create new capabilities by fostering and sustaining a long-range program of applied research in nuclear and ion propulsion, in the application of magnetohydrodynamics to re-entry and vehicle problems, in advanced propellant chemistry, in the use of plasma physics, in advanced communication techniques—all of these and many more must be pursued with the intent of direct application. We must clearly recognize the danger and potential waste in a program that does not provide in an orderly manner the creation of new knowledge to replenish and expand that which we are now using. In fact, the individuals responsible for any large program have an obligation to replenish the basic technical knowledge which made such a large program possible in the first place.

Next, the question should be asked: Are we evolving a space program whose architecture is sound and whose goals are both attainable and in our nation's and the world's best interest? At the present, how susceptible are we to special pressures, to political expedients, and to the random direction of an international contest with our opponent calling the shots? We must, every one of us, admit the fact that we are indeed competing with

(*Continued on page 54*)

Richard H. Parvin, MIAS
Minneapolis-Honeywell Inertial Guidance Center

The Earth and Inertial Space

Part I—Motions of the Earth

A WELL-BEHAVED inertial system provides its outputs by sensing the forces acting on its mass. According to Newton's laws, these forces will be proportional to changes in the velocity and changes in direction of this mass. The reference frame, therefore, is "inertial space." Inertial space can be considered as being the same as celestial space (where the positions of the stars are considered fixed), with the exception that inertial space may have a *constant linear velocity* with respect to celestial space.

The earth, however, is not fixed in inertial space. A coordinate frame $\hat{i}, \hat{j}, \hat{k}$ fixed to the surface of the earth at point O, but inertially stabilized to space, would appear to describe the pattern shown in Fig. 1 because of the motion of the earth. Notice that it appears to be rotating about the celestial polar axis (parallel to the earth's polar axis) but that it actually remains fixed with respect to the stars.

Principal Motions of the Earth

We know that the earth has several distinct motions. Some of these are of no significance to an inertial system because they are very small, even when compared to the accuracies of present-day inertial components. The principal motions are (1) daily rotation about the earth's axis, (2) annual revolution about the sun, (3) precession, (4) wandering of the poles, and (5) motion in the galaxy.

Daily rotation, of course, is 360 deg. per day (west to east) with respect to the sun. But because of the annual revolution of the earth in its west to east orbit around the sun, the earth has to turn *more* than 360 deg. in space to complete one revolution with respect to the sun (Fig. 2).[1] The time required to turn 360 deg. in space (or with respect to the "fixed" stars) is called the *sidereal day* which is 23 hours, 56 min., 04.1 sec. long.[2]

The assistance of the U.S. Coast and Geodetic Survey and of the Smithsonian Astrophysical Laboratory in reviewing the technical information herein is greatly appreciated, as is the assistance of Mrs. Barbara Scott in the calculations, and Barnet Bethel in preparing the illustrations.

Mr. Parvin is an aeronautical engineering graduate of Alabama Polytechnic Institute and has done graduate work in engineering management. As an Air Force pilot, Mr. Parvin flew strategic combat and MATS transport missions. Most of his engineering career has been in inertial navigation systems and support equipment and as a project engineer of aviation training devices, including a twin-engine flight simulator. He has been active in public relations, contract administration, and engineering personnel. He is now Senior Systems Engineer, Aeronautical Division, Minneapolis-Honeywell.

Irregularities in Orbital Velocity

We know the earth's orbit is slightly elliptical, with the sun at one focus of the ellipse. Its distance from the sun varies from $1.470(10^{13})$ cm. in January to $1.520(10^{13})$ cm in July.[3] From Kepler's laws (a radius from the sun to a planet sweeps equal areas in equal time), the orbital velocity of the earth is calculated to be 68,970 m.p.h. at its perigee in January and 66,535 m.p.h. at its apogee in July, as shown in Fig. 3. This is a translational motion and not a rotation of the earth in inertial space because the earth's axis remains relatively fixed in spatial orientation as the earth orbits. Furthermore, while the change in velocity shown in Fig. 3 is a real acceleration, it will not be sensed by inertial components which cannot distinguish between acceleration and mass attraction. The acceleration is caused by the mass attraction of the sun, and the sun will equally attract the "seismic mass" of the accelerometer.

Precession

The polar axis is inclined 23 deg. 27 min. to the plane of the ecliptic[4] or orbital plane. Because of *precession* the polar axis describes a cone about the perpendicular to the ecliptic as pictured in Fig. 4.[5] This is caused by the mass attraction of the moon, sun, and planets on the bulges at the equator. These attractions, while attempting to pull the earth into perpendicular, actually cause it to precess because of the gyroscopic action of the rotating earth. This motion is very slow—one east to west revolution in 25,800 years.

An inertial navigation system inherently senses angular velocities and linear accelerations in terms of a space coordinate system. To use this information to navigate on or near the planet earth requires a knowledge of the significant motions of the earth and of its shape.

Part I discusses the several known and accurately measured motions of the earth in inertial space. It is shown that the only one sensed by an inertial navigation system is its sidereal rotation about the polar axis. Part II will describe the shape of the earth and its effect on gravity, the Schuler period, and the length of a degree of latitude.

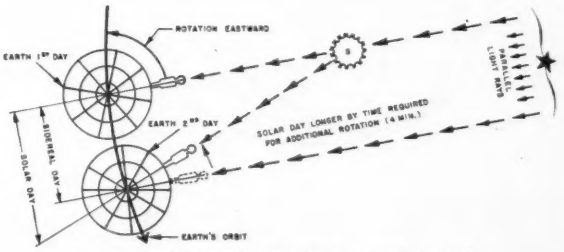


FIG. 2. Relationship of solar day to sidereal day.

However, this annual drift of 50.2 sec. of arc[6] is sufficient to cause the earth to complete a seasonal cycle (when the sun moves from latitude 23 deg. 27 min. N to 23 deg. 27 min. S and back) twenty minutes before it has completed a sidereal year,[7] or one revolution about the sun. The polar axis has precessed about 30 deg. since early astronomical observations and is now nearing its closest point to Polaris.

Nutation

The relative motions of the moon, sun, and planets cause a slight irregularity in the precession rate. This irregularity is called *nutation* and is too small to be of consequence to inertial navigation, having one component smaller than 10 sec. of arc with a period of 19 years and another component smaller than 1/2 sec. with a fortnightly period.[8]

Wandering of the Poles

So far we have considered only motions of and about the earth's polar axis with respect to inertial space. One other motion of interest is the periodic wandering of the poles on the earth's surface. There appear to be two periods involved—an annual period and a Chandlerian period of 14 months. As Fig. 5[9] shows, the total excursions stay within ±40 ft. of the mean polar axis.

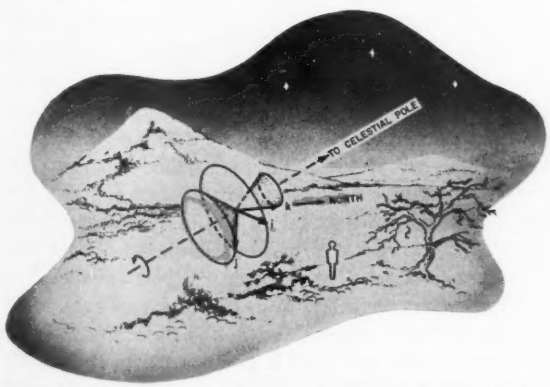
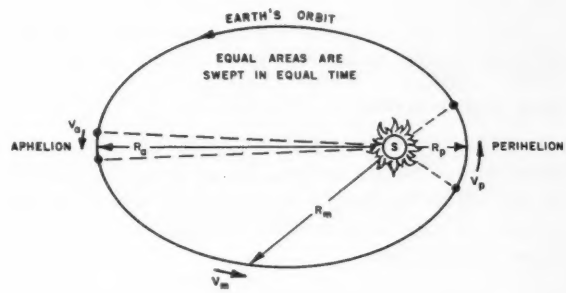


FIG. 1. Apparent motion of a space-stabilized reference frame—$\hat{i}, \hat{j}, \hat{k}$.



R_m = 60.724 (10^6) N.M. V_m = 57,853 KTS.
R_p = 79.374 (10^6) N.M. V_p = 58,866 KTS.
R_a = 82.073 (10^6) N.M. V_a = 56,571 KTS.

FIG. 3. Variations in earth's orbital velocity.

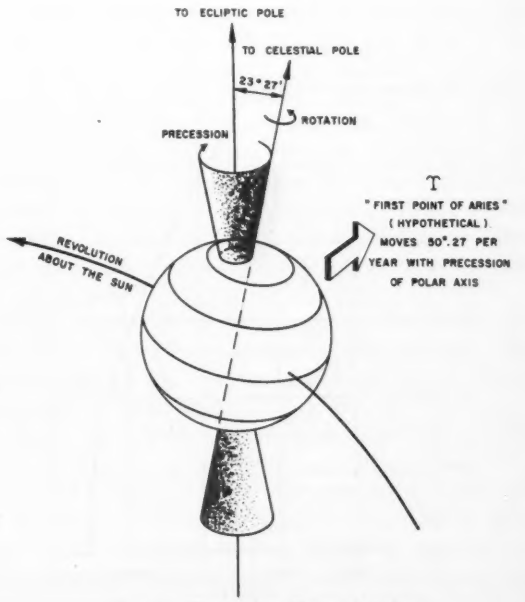

TO ECLIPTIC POLE
TO CELESTIAL POLE
23° 27'
ROTATION
PRECESSION
"FIRST POINT OF ARIES" (HYPOTHETICAL) MOVES 50".27 PER YEAR WITH PRECESSION OF POLAR AXIS
REVOLUTION ABOUT THE SUN

FIG. 4. Precession of earth's axis.

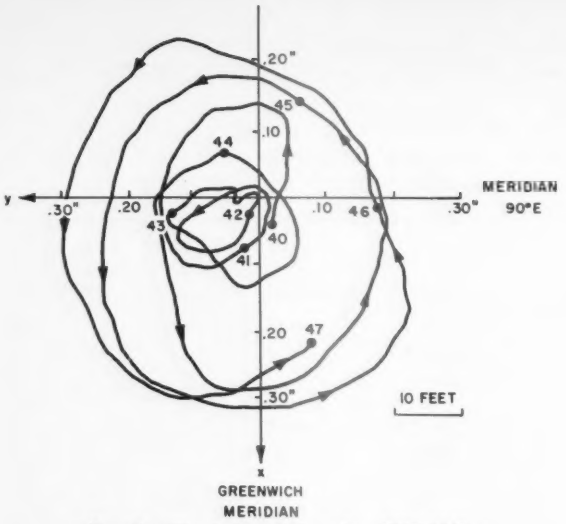


FIG. 5. Wandering of the poles, 1940–1947.

But this means that a geographical position on the earth's surface can move about with respect to the earth's inertial motions.

Solar System Motion

Not worth getting excited about—but the earth, along with the solar system, has an interesting spiral motion within the galaxy, estimated at about 1 revolution in 200 million years[3] with a tangential velocity of about 29,000 knots.

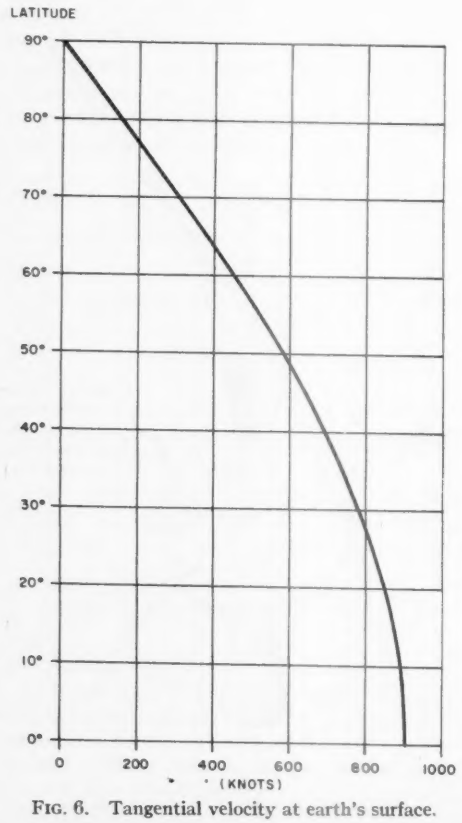


FIG. 6. Tangential velocity at earth's surface.

Earth's Rate in Inertial Space

As far as inertial navigation is concerned, then, the earth's angular rate of rotation in inertial space is essentially the sidereal daily rotation (15.04107 deg. per hour).

Coriolis Acceleration

The tangential velocity at the earth's surface due to its daily rotation is 904.1 knots at the equator and reduces to zero at the poles (Fig. 6). Any vehicle moving northward would appear to veer to the east unless it were constrained to the earth's surface. This *apparent* eastward acceleration is the Coriolis effect. Any constraint to force the vehicle to reduce its eastward tangential velocity to stay on the same earth's meridian is a *Coriolis correction*. It is said that a train engine's right wheels wear out first because of the constraining effect of the tracks when the train is moving northward and the "nudging" effect of the tracks to increase the train's eastward velocity when the train is moving southward.

In vector notation, the apparent acceleration is

$$A_c = -2\omega \times V$$

where A_c is the Coriolis acceleration in ft. per sec.^{2}, ω is the earth's rate of rotation in rad. per sec., and V is the vehicle's velocity in ft. per sec. Expanding this equation in terms of earth's coordinates,

$$-2\omega V_n \sin Lt = A_e$$

$$-2\omega V_e = A_g \cos Lt - A_n \sin Lt$$

$$-2\omega V_g \cos Lt = -A_e$$

(*Continued on page 47*)

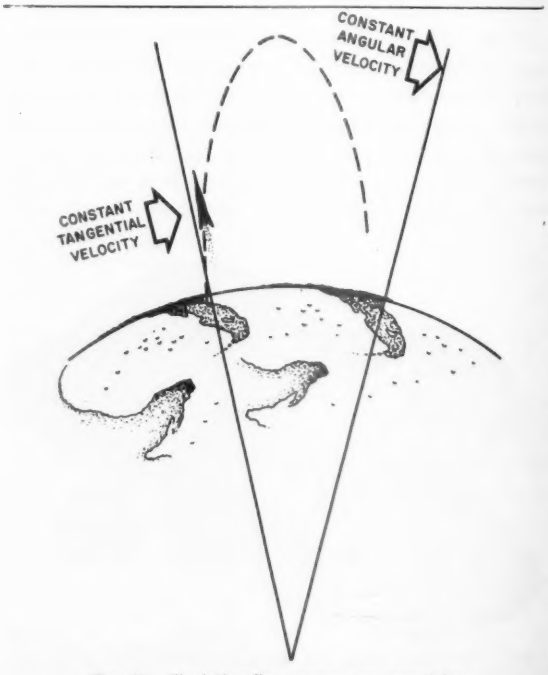


FIG. 7. Coriolis effect causes westward lag.

The new developments in aircraft and missiles create a need for technical reorientation in all respects and for understanding of the international competition connected with these developments.

Flight Into SPACE

Hollingsworth Franklin Gregory, AFIAS
Midwestern Instruments, Inc.

"OUR SPECIES is the only creative species, and it has only one creative instrument, the individual mind and spirit of man." This quotation from John Steinbeck seems particularly appropriate since all technical achievements of man are an extension of his mind. The development of the mind is achieved through the senses. For maximum development, however, man has had to extend the capability of his unaided senses by instruments and tools.

Just 2 years ago in San Diego, Calif., I attended the first Astronautics Symposium, sponsored by the Air Force Office of Scientific Research and by Convair, A Division of General Dynamics Corporation. To me, then as now, "horizons are truly unlimited." The great potential of air power loomed larger and brighter than ever before and is even brighter today. Our group was referred to by some as "Magellans of Space," although my conservative prediction that man could put a device near or around the moon within 5 years created some displeasure in high positions of the Department of Defense.

Reference is made to this only to illustrate the difference of the environment existing then and today for the development and profitable exploitation of the possibilities of the potentials of air power. Two years ago, to have seriously considered sending any device to, or near, the moon would have been classified as completely unreasonable. Any proposed exploration of the vast and challenging area of extra-atmospheric flight would have been disapproved. Today such endeavors are encouraged. This is, indeed, progress. For, if one recalls, after a decision was made to develop a missile of the intercontinental ballistic type, in 1947, with a wave of economy in defense, it was reversed by a cancellation of the very project that today is the backbone of our intercontinental ballistic missile effort. The project was later revitalized, and today we have the Atlas in orbit and many successful test flights in the development toward an effective intercontinental ballistic missile.

Visionaries who speculated on man's conquest of space have been succeeded by scientists and industrialists in the race for flight into space. Today, in my opinion, we are in a race and, if not, we certainly should be in that race in our attempts to keep technologically ahead of Russia.

Brig. Gen. H. Franklin Gregory commanded the U.S. Air Force Office of Scientific Research in Washington, D.C., from 1956 to his retirement in 1958. His richly productive military career started in San Antonio, Tex., at Brooks and Kelly Fields in 1928, and included 4 years as air attaché at the American Embassy in Paris.

General Gregory is listed in *Who's Who in America* as a nationally known aeronautical and astronautical authority. He has many important "firsts" to his credit; he is the first military man to fly the wingless autogiro; first to fly the helicopter; and first to make helicopter landings on ships at sea. He exceeded all world records in testing the world's first practical helicopter—the Sikorsky XR-4. Development of scientific instruments for national defense is General Gregory's primary concern as Vice-President, Assistant to the President, of Midwestern Instruments, Tulsa, Okla., since his retirement, October 31, 1958.

Fortunately, in 1956, before the meeting at San Diego, a few forward-looking individuals had planned a flight into space. This flight was to be made by a small 4-lb. instrumented package. The package was designed as a scientific probe into the unknown—into space—to altitudes higher than man had ever thrust any device before. The need for information concerning the envelope surrounding us was apparent to some and urgent to others. The probe was made to obtain scientific information relative to the earth's magnetic field and cosmic radiation intensities for the height of one earth's radius—4,000 miles. There were six probes to be launched. These probes were being launched in the Pacific in September and October, 1957, under the name of "Project Farside." In October, 1957, the Russians launched "Sputnik I." Our "Project Farside" contributed to the prestige of the United States in the community of nations.

Since "Sputnik I" we have experienced a demonstration of an alarmed and aroused public opinion. The Department of Defense has established the Advanced Research Projects Agency to ensure that we attain a leading military capability in space as quickly as possible. This agency represents a large stride in the direction of adequate military preparation for the space age. It is making contributions in vital areas of establishing worth-while projects, setting priorities, coordinating efforts, and guiding the many participants in these undertakings.

Congress has enacted a law establishing the National Aeronautics and Space Administration for the purpose of expanding human knowledge of phenomena in the atmosphere and space, and to preserve the role of the United States as a leader in aeronautics and space science and technology, and in the application of this knowledge to the conduct of peaceful activities within the earth's atmosphere and space beyond.

Several attempts have been made to reach the moon. To date, the ultimate objective has not been achieved. However, altitudes were obtained far in excess of early attempts. The Russians have been successful in launching a device which is in orbit about the sun. In my opinion, their objective was the moon. Their attempt to reach it, one might say, was a little strong, where America's attempt was a little weak, in relation to speed. An object, to be captured by the moon's gravitational field, must travel at a speed which permits it to become an orbiting captive of the moon, and not at an excessive speed which would plummet the device through and beyond the moon's gravitational field. In other words, hitting the moon or orbiting around the moon requires extreme precision.

One American way to solve problems seem to be to establish additional headquarters or agencies. Often the original structure, if given a little understanding and support, will solve the problems with greater efficiency and effectiveness. In America, we have but to have a decision from the proper authority. Once the decision is made, it is but a matter of marshalling the forces from our vast technological potential to make the necessary effort in order to solve the problem, whether it be to construct intercontinental ballistic missiles or to visit the moon.

Man in Space

Since man's first successful powered flight at Kitty Hawk, only 55 years ago, he has striven to reach higher altitudes and to fly greater distances at faster speeds. Today man is not content with having already visited altitudes where more than 90 per cent of the mass of the earth's atmosphere was below him, of flying at speeds in excess of the speed of sound, and of covering global distances. This progress already is a tribute to the airman whose skills have played a major role in making these achievements possible. Today he is probing space with devices that travel at fantastic speeds and at altitudes where there exists a nearly complete vacuum. The extent to which these devices will replace manned devices will be determined in some degree by the operational role in which the unmanned devices will be employed.

Serious preparation is now under way for man to enter the area already being probed by missiles and rocketed devices and satellites. Much knowledge is being assembled for entering this field. However, much more knowledge is required. A tremendous amount of energetic effort in research and development is needed to increase the total of man's knowledge in these complex areas. I will quote Col. Paul A. Campbell, who was my special assistant for medical research when I commanded the Air Force Office of Scientific Research: "It can readily be seen how aviation medicine makes a smooth transition into space medicine, and that the problems of space medicine, for the most part, are those of aviation medicine projected into more hostile situations and environments. The human parameter of aviation medicine and space medicine, in general, is the same." He supports the thesis that one phenomenon surrounds our earth with varying characteristics at various distances from the surface. Quoting my friend, Capt. Norman Lee Barr, Chief of Project Research Astronautics Medicine for the U.S. Navy, "Attempts are being directed toward making the conditions encountered by man in space as similar as possible to those which he experiences on earth. The limits of the physiological variables necessary for survival are known. The levels of these variables needed for comfort of living are either known or can be estimated fairly accurately."

Physiologically, man lives normally in a pressure of approximately $14\frac{1}{2}$ lbs. per sq. ft. The gas which he breathes is approximately 21 per cent oxygen and 0.03 per cent carbon dioxide. The most comfortable temperature seems to be around 70°F. Scientists and airmen are exploring daily the effect of acceleration forces and the effect of weightlessness. The problems of toxic gas and cosmic radiation will have to be solved if man is to function effectively. The problems of fatigue, isolation, and confinement certainly will be serious ones for consideration.

All man's experience is obtained through his senses—namely, sight, touch, hearing, etc. There are no measuring devices in these senses. There is no basic unit of measurement by which man can tell the magnitude of what he senses. Since there is no unit of measurement, man tends to measure changes in those things that he observes, those that he detects, in terms of the magnitude of the thing being detected. If I were to hold in my hand one gram of weight, I could feel it; I could perceive it by my sense of touch. If I hold several pounds of weight and add one gram of weight on top of the several pounds, I can detect no change—the percentage of change is too small to detect. On the other hand, if I add several pounds to the first, I can detect the addition easily, for the percentage of change is great.

Another example is that of listening to a musical note. If the note is varied by only one cycle, man cannot detect the difference. But, if it is varied by many cycles, the ear can easily detect the difference in pitch. Still another example is the intensity of sound. The smallest change in sound level the human ear can normally detect is a 25 per cent change. The difference is known as a decibel. On the decibel scale the difference in sound level between a barely audible whisper and a normal conversational voice amounts to some 60 db. Such a change represents a change in the actual amount of energy on the eardrum of approximately one millionfold.

It was not long ago that a scientist, engineer, or technician was a man who aided his mind, his hands, and senses with relatively crude instruments and tools to

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discover scientific facts. Today he requires extremely advanced instruments and tools to extend the capabilities of his bare hands and his unaided senses. These instruments and tools are more reliable, more dependable, and more accurate, yet more complicated and complex. There was a time when an organic chemist checked each stage of synthesis by relatively simple methods—melting points, boiling points, perhaps a few simple analyses. Today he uses infraspectrometers and obtains much more accurate and reliable information in a much shorter time.

The situation is the same in any area of science or technical development. For example, technical physicists who in the past needed only pencil and paper, and perhaps a desk calculator, now require many hours of electronic computer time to check their technological computations. The simple electroscope with which ionizing radiation was discovered has been replaced by scintillometers, high-speed computers, and multichannel differential analyzers. The types of solid-state crystals in which we are interested today have to be grown in high-temperature vats with precision withdrawing apparatus instead of glass beakers.

Instrumentation in Space Flight

In the early days of aircraft manufacturing, the airplane was built by the designer from his theoretical knowledge, prior experience, and engineering intuition. The test pilot then flew it and recorded various readings from the dials of instruments on his control panel. While he flew the plane in altitudes producing various stresses and strains, this information was recorded on a pad strapped to his knee. Today the flight testing of a modern plane involves taking hundreds of thousands of measurements.

When rockets and missiles are tested, even more measurements are required. These measurements today are made by a highly specialized, reliable, and accurate instrumentation. When a missile is ground-tested today, instruments record more information during a simulated flight than an engineer or technician personally could record in a lifetime. Since the flight of the Wright brothers, man has truly extended the capability of his senses by instrumentation. Flight into space continually will require more complex instruments with greater reliability and accuracy.

Man learned early the necessity of developing instruments which would permit him to sense more accurately his environment. It was necessary to know when that gram was added to several pounds and when the pitch of the note was changed by a few cycles. As man has progressed, complexities have increased. Progress is, in fact, similar to a chain reaction. The technical achievements of today result from the progress of yesterday. Tomorrow's understanding of fundamental natural law and progress will be based on the understanding obtained and progress made today. As fundamental laws are understood and technical progress is made, new technologies result. A technical development creates new problems. Solutions to these problems bring man face to face with other new problems. It can be said that our progress is the result of problems. When problems cease to exist, progress will cease to be made.

Again it must be remembered that there is a single continuum that surrounds the earth. Air and space are convenient ways of describing parts of what is really a unified phenomenon. All spacecraft departing from earth will have to be aircraft on departure and on arrival, if the craft is to land on earth. Solutions to certain problems of aircraft today are then applicable to spacecraft of tomorrow.

There are serious problems today in the stability and control of aircraft and missiles in the supersonic range, and many more in the hypersonic range. There are problems in aeroelasticity and there are serious structural problems. The phenomenon occurring in our jet airplane today as a result of vibration from sound energy is not completely understood. We have these problems as the result of technical development and progress. As we enter the age of space exploration, there are problems we have not even suspected. The requirement for more accurate techniques of measurement and for greater speed in measuring will continue to grow greater. We probably will have to develop entirely new instruments to measure things now unknown. The invention, development, and building of scientific instruments has become a field of scientific investigation in its own right. The field of instrumentation is increasing in importance as we prepare for flight into space.

The intercontinental ballistic missile, the rocketed scientific probes, and satellites which opened an entirely new area of flight beyond the earth's atmosphere, coupled with the tremendous development of nuclear reaction and their concomitant physical, social, and physiological impact, demands that no stone be left unturned to accelerate and expand our never-ending source of new knowledge. Proper instrumentation will be essential in this search. Our country today faces a grave threat to our continued way of life. I know of no way in which we can leap over it, ignore it, or wish it away. The most recent demonstrations of Russian technology—placing a satellite into orbit about the sun—give evidence that we must be alert to this threat. We must face it squarely. As Americans, we always have taken great pride—and justifiably so—in our ability as a nation to rise rapidly and vigorously to any challenge. This has been possible in the past because of our unsurpassed industrial and economic potential, reinforced by superior scientific and technical know-how. It is absolutely essential that we maintain a scientific lead over any would-be aggressor. The only way we can assure continuing peace is through our mastery of an overwhelming retaliatory capability.

Time is a precious commodity, and the use of time wisely to enhance our technical capability is one of the best investments I know in the security of our country. It is within our capability to do that which we desire. Technical progress is merely the extension of the mind of man. We will make our flight into space.

There does not exist, it seems, a clear-cut standard by which we can determine an adequate level for our space program. The standards we have now are the military capability of potential enemies and national scientific prestige.

The GROWING PROBLEMS in the Space Program

H. Guyford Stever, FIAS
Massachusetts Institute of Technology

Dr. H. Guyford Stever, Associate Dean of the School of Engineering and Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology, has made numerous contributions to the field of aeronautics. In addition to his active role in teaching and administration at M.I.T., he has rendered service to the USAF on several advisory groups, culminating in his service from 1955 to 1956 as Chief Scientist of the Air Force. He has been a member of the USAF Scientific Advisory Board since 1956, and is now Vice-Chairman. He has recently been appointed Chairman of the NASA Research Advisory Committee on Missile and Spacecraft Aerodynamics. Dr. Stever was graduated from Colgate University in 1938, and in 1941 he received his doctorate in physics at the California Institute of Technology, where he did research on cosmic rays and electronics for Geiger counter experiments. In 1958 he was awarded an Honorary Doctor of Science degree by Colgate University.

THE FIRST YEAR AND A HALF of the space age has been marked by substantial accomplishments along certain lines. Organizationally, the importance of astronautics has been recognized at the top level of government with the formation of the National Aeronautics and Space Council under the President's chairmanship. The establishment of the National Aeronautics and Space Administration with the responsibility for the nonmilitary aspects of astronautics, and the Advanced Research Projects Agency with the responsibility for the military phases of astronautics has rapidly brought into being the agencies which can push forward along these lines. The budget has also been adjusted upward—it was between 100 and 200 million dollars in the last fiscal year; this year it is expected that expenditures will be 700 to 800 million dollars; it is planned next year to have a budget between 800 and 900 million dollars.

In addition, there have been a number of other organizational moves within the government to take care of the expanding problems of space. The National Academy of Sciences has formed the Space Science Board with twelve *ad hoc* committees covering a wide variety of scientific fields related to space. This board will ensure wide participation of scientists in exploiting our new space flight capabilities in scientific research. Congress has adjusted its organization to a continuing and important effort in space by establishing permanent committees on astronautics; a host of other units of the government, which are touched in any way by space considerations, have adjusted themselves accordingly. A good example of the latter is the recognition of the long-term future potential of nuclear-rocket propulsion, which has become an important activity under the jurisdiction of the Atomic Energy Commission.

Industry has also converted itself to the demands of the space age. Many companies that had not already become deeply involved through the ballistic missile programs of the military services have assembled talent to capture a role in the astronautics effort of the country. Even academic institutions, notably somewhat conservative, have begun to adjust their teaching in the aeronautical field to give a much more prominent place to the promising field of astronautics.

All of this leads to large questions: have we overestimated or underestimated the importance of the field of astronautics, our technical capabilities in the field, the amount of financial support, government organization and coordination required to meet our national objectives in this field? The answers to these questions will not be found quickly. However, they deserve the continued concentration of all interested parties.

Our Current Technical Ability to Meet the Conceived Space Missions

The variety of space vehicles which have been conceived is great. The best known are the ballistic missile and the earth satellite. In between the missions of these two vehicles, there are a number of other vehicles: the boost-glide vehicle, such as the X-15; the semiballis-

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tic vehicle, sustained in its curved path partly by centrifugal reaction and partly by aerodynamic forces generated in the rarified upper atmosphere; the semi-satellite, or satelloid, a satellite operating in a region where the drag of the rarified earth's upper atmosphere would decelerate it quickly except that periodic spurts of a small rocket motor are used to keep it orbiting.

Beyond satellites, there are artificial asteroids of the sun, satellites of the moon, probes and satellites of other planets, vehicles to land on and take off from other planets and the moon, and, finally, true spacecraft which can maneuver at will throughout the solar system.

For many of these missions the intensive ballistic missile program of the military services has furnished considerable equipment, equipment either already developed and now being thoroughly tested or in an advanced stage of development. In the field of rocket propulsion, for example, taking the key technical field of space flight first, ballistic missile rocket boosters furnish a capability to carry the space flight program many years into the future. The first American satellites, Explorer and Vanguard, had initial stages which were not high in thrust capability, the Vanguard 28,000 lbs., and the Explorer, using the Jupiter C, 75,000 lbs. Vehicles designed around those rocket motors succeeded in putting payloads in the range of 15 to 30 lbs. in satellite orbits at normal altitudes around the earth. However, using either of the two existing intermediate-range missiles, Thor or Jupiter, with rocket thrusts of about 150,000 lbs. for initial take-off weight of about 100,000 lbs., the payload capability for a 300-mile-altitude satellite can be in the range of 1,000 to 2,000 lbs. Either of the two intercontinental ballistic missiles, Atlas and Titan, in which the initial rocket stage has a total thrust of more than 300,000 lbs., can be used to establish a 300-mile satellite in the 2,000 to 8,000 lbs. payload category.

Going on to farther-reaching space missions, vehicles boosted by either of the two intercontinental ballistic missiles could carry 500 to 2,500 lbs. to the 22,400-mile altitude which is required by a hovering satellite; they could also boost a moon impact vehicle of 600 to 3,000 lbs., establish a moon satellite of 300 to 1,500 lbs., establish a moon landing of 200 to 1,000 lbs., go to the region of Venus and Mars with 500 to 2,500 lbs., or the region of Jupiter with 300 to 1,500 lbs. Beyond the ICBM boosters, rocket engines in the million-lbs.-thrust category are under current development. Presumably, these will be available in a few years. Rocket vehicles based on such rocket motors can put 25,000- to 50,000-lbs. payload weight into a 300-mile satellite orbit.

Offhand, it appears that there is no need for new developments in propulsion to accomplish the space flight program. This is not so. The liquid-propellant rockets now at hand or soon to be at hand, though light in weight, have rather low specific impulses and are used best to establish a space mission by setting up all of the required kinetic energy during the initial burning, employing only small correcting spurts of rocket power later. They do not permit great flexibility in maneuver which will be desired in later space missions. Ion engines, nuclear rockets, and other reaction motors, if developable, will be used.

The development time for these engines is clearly going to be quite long; unless started now, they will not be available when wanted. Furthermore, one cannot fall back on the large resources which were available from military sources for the development of the current liquid-propellant rocket motors. Most of the more obvious urgent and immediate needs of the military seem to be quite well met by existing or soon-to-exist liquid-propellant rocket motors. In fact, the urgent ballistic missile rocket developments of the military seem to be tending away rather than toward those required for the more remote space missions. Smaller, more reliable, more easily handled ballistic missiles and satellite vehicles for reconnaissance appear best designed around rocket boosters, which are not necessarily the best for the extreme space missions. Though both the military and nonmilitary space activities will profit from each other's rocket developments, it is unlikely that identical rocket engines will continue to serve both optimally.

In the area of guidance, the nonmilitary space program also inherits a great deal from the ballistic missile efforts of the military services. This can be seen by an analysis of the required accuracy for a ballistic missile mission. Although this is classified in its detail, a simple calculation indicates that an error of 1 ft. per sec. in the burn-out velocity of about 24,000 ft. per sec. of a ballistic missile designed to go about one-fourth of the way around the earth, will result in a miss of about 1 nautical mile. Knowing roughly the radius of action of nuclear warheads, one can guess that this range of accuracy is the objective of ballistic missile developmental programs. Presumably, such an accuracy, if not already reached, is within reach. What does an error of 1 ft. per sec. mean in terms of more remote space missions? Such an error represents a departure from circularity of orbit of an earth satellite of about 1 mile if the satellite is in the altitude of 1,500 miles. That same error of 1 ft. per sec. in final velocity represents a miss of something less than 100 nautical miles in shooting at the moon, an error of 20,000 to 25,000 nautical miles in shooting at Mars or Venus, of 65,000 nautical miles shooting at Jupiter. In some of the earlier experiments with these objectives, such accuracies are tolerable. So, for the one-shot type of space mission, the accuracy of guidance obtainable in ballistic missiles seems sufficient for a number of important jobs.

Again, one can easily be misled by the technical situation. Current guidance will be good for only a few years into the future. When demands are extended to include mid-course or final guidance, a whole new array of equipment must be developed: inertial elements, star

trackers, vehicle-contained radars to measure distances and positions of remote planets, terminal guidance devices to locate the horizon of a planet as it is approached, altitude-measuring devices, and terrain feature sensors. For many of these devices, though they will employ some of the components required for the more urgent military space missions of the future, a great deal of the developmental effort must be carried on the basis of the nonmilitary space mission program. Again, there is a requirement to start these developments early.

In the design of the vehicles to enter the atmosphere of the earth or any other planet, there is a clear overlapping between military and nonmilitary space activity. Except for the elements of the heat-sink and ablation re-entry techniques, the space program does not inherit a great deal from the ballistic missile program at the present stage. There is much to be done, especially in entry techniques which permit maneuver.

In the field of tracking and communication, and in the establishment of the necessary ground-station network, the nonmilitary space effort does not inheret a sufficient capability from the previous military efforts. There are, of course, large military developments of detection and tracking equipment for the antiballistic missile mission. These radar developments will be of great use in the space mission, but will not permit tracking of vehicles far away from the earth, for the ranges to which a radar can track a passive vehicle are limited to the order of thousands of miles. Long-range radio tracking equipment must be developed.

Furthermore, the locations of the ground tracking and communication stations that will be needed for a nonmilitary space program do not coincide with the locations of stations involved in a military tracking and communication network. For more distant space missions, the equatorial belt of the world is generally desirable, whereas military placements of ballistic and antiballistic stations are concentrated in the northern parts of the Northern Hemisphere.

In summary, from the standpoint of our total technical ability to design, build, and operate successfully the many space vehicles which are now conceived, we find that we have a capability of carrying on nonmilitary space operations for some few years into the future, due to an inheritance of equipment from the ballistic missile program of the military services, combined with the rather easy and obvious development extensions of other apparatus. However, for the more remote operations in space, new devices are needed, the development time of which will probably exceed the time available even if a major development in the field is started now. Furthermore, many of the developments will not fall naturally out of high-priority military developments.

The Uses of Space and Growing Problems of Program Balance

During the last year, concepts and understanding of the important uses of astronautical capability have been formed. There has never been any question of the military importance of some of the phases of astronautics. Ballistic missiles, reconnaissance satellites, semiballistic bombardment, and reconnaissance craft, and a number of other devices have been considered most important to the military mission and well worth exploitation.

The split between military and nonmilitary space effort, while desirable in many ways, poses a serious problem to military planners. It is almost certain that, as space capability grows, new military uses of space, not now foreseen, will become apparent. In a divided program, the military services will find it more difficult to grasp the significance of these quickly and will, because of only partial control of the program, find it harder to marshall all the resources to capitalize on these ideas.

In the field of scientific research, the last year has brought forth a much clearer examination of the types of experiments which can be performed by space vehicles. Astronomy and physics clearly are the first fields to benefit, but meteorology, biology, and a number of others follow in close line. However, it now appears that the expected developments of current space vehicle capabilities will actually outrun the development of the scientific apparatus for use in the research program. To date, the scientific experiments that have been performed in satellites have been quite elementary. It is true that a few have shown a large payoff. But there is a very long way to go in the development of scientific apparatus to take advantage of our space flight capability, and this effort seems to be going too slowly.

Another series of related important uses of space flight which has become clearer during this past year is the employment of satellites for communication relay stations, for navigation, and meteorological satellites. These practical uses of our space capability to improve our life on earth seem to be within easy reach, at least with respect to the development of the space vehicle capability and the development of the equipment to go aboard. The equipment is not at hand, but a reasonable program can produce it. It will probably come so rapidly that there will soon come a time when equipment development for these satellites will not be the most urgent problem, but that rather government regulation and control will be the prime issue. Progress in national and international organization to meet these problems has not yet been very substantial.

Finally, there seems to be no clear-cut standard by which we can determine an adequate level for our space program. It is clear that we want to proceed forward along all the lines I have mentioned, but what is the priority? How fast should we go along each one? Is one much more important than the other? On the military side, we have the military capability of potential enemies with which we must compare our own efforts. On the scientific and exploratory side, not only is there the general desire of scientists, explorers, and adven-

(*Continued on page 54*)

Artist's painting of the X-15 during later stages of engine burning at threshold of space flight phase of a mission.

SPACE FLIGHT IN THE X-15

Clayton C. Clark, Jr.

North American Aviation, Inc.

The objectives of the X-15 program are primarily concerned with the problems resulting from the flight conditions encountered during re-entry from space flight; the design emphasis has been placed accordingly.

Clayton C. Clark, Jr., a native of Minnesota, graduated from the University of Minnesota in 1945 with a Bachelor of Science degree in Aeronautical Engineering. He was an aerodynamicist with the Los Angeles Division of North American Aviation for 6 years. In 1957 he was assigned to the Office of Plans and Programs and is responsible for strategic and research systems in that office, in particular for the X-15. Prior to joining North American, Mr. Clark was with Transocean Air Lines as a flight-test engineer and analyst at the Landing Aids Experiment Station in Arcata, Calif.

MAN TRAVERSED the face of the earth for thousands of years at a maximum speed of 10 m.p.h. on foot until the domestication of the horse about 15,000 B.C. extended this speed capability to 35 m.p.h. on horseback. He achieved a speed of 120 m.p.h. by 1900 A.D. with the steam locomotive. A record altitude of 72,395 ft. was reached by a man in a balloon gondola in 1935, and a speed record of 671 m.p.h. was established in 1950 in an operational jet fighter airplane. Five years later a man had flown a research airplane at approximately 1,400 m.p.h.

Today man is poised on the threshold of space flight, anxiously awaiting the final preflight instrumentation and check-out of the airplane that will give him a speed and altitude capability of over 3,600 m.p.h. and 100 miles, respectively. This rocket-powered airplane, known as the X-15, was designed and built by the Los Angeles Division of North American Aviation, Inc., for the Air Force, the NASA and the Navy. The airplane (Fig. 1) was unveiled in Oct., 1958.

The objective of the X-15 research program is to explore the flight spectrum to be traversed by future generations of operational aircraft, particularly the problems associated with re-entry into the earth's atmosphere after an excursion through space.

The knowledge gained will be used in the design of these future high-speed, high-altitude air vehicles. The objective may be divided into four major consider-

FIG. 1. Scott Crossfield, who will be the first man to fly the X-15, is shown in an especially designed full-pressure suit.

ations: (1) demonstrating the integrity of structural designs under intense temperature conditions caused by aerodynamic heating, especially during re-entry into the earth's atmosphere, (2) the stability and control (Fig. 2) characteristics to be required for flight in both the earth's atmosphere and space, (3) correlation of simulator and flight data and establishment of a basis for projection of requirements for future studies of this nature, and (4) the physiological and psychological factors to be considered for the human occupants, such as acceleration and deceleration forces, weightlessness, confinement in space suits, crew escape, etc.

The limiting design considerations involved in the development of the X-15 in order to assure a timely, economic, and reliable vehicle were time, state of the art, safety, and cost. The flight test results must be available appropriately in time so that they can be incorporated into the design of these future air vehicles. Therefore, the development of various advanced subsystems was not to cause undue delay in delivery of the air vehicle. This required the creation of the operating environment where necessary, such as in the instrumentation bay. Safety for the pilot involved many new designs and engineering efforts, such as a new pressure suit and ejection seat. Reliability and reasonable cost were attained by providing the minimum practical vehicle capable of satisfying the mission requirements.

The X-15 Airplane

Configuration

The X-15 is essentially conventional in external appearance with the exception of the wedge-shaped upper and lower vertical tail surfaces and the side-fairings running almost the entire length of the fuselage.

The wing is a mildly swept ($C/4 = 25°$) tapered symmetrical airfoil having a thickness of 5 per cent. The solid leading edges of the wing have a radius of approximately 3/8 of an inch and act as a heat sink rather than the sharp leading edges for reduced drag of a current supersonic fighter airplane, such as the F-104. The leading edges are in segmented sections to avoid spanwise thermal stresses. The flaps in the wing are used for landing.

The horizontal tail panels are deflected simultaneously for pitch control and differentially for roll control. These panels have negative dihedral to get them out of the wake of the wing. The "rolling tail" was incorporated because the actuators for conventional ailerons would have been subjected to unduly high temperatures in the wing, and they also would have been sufficiently large to protrude outside the mold line of the airfoil section.

The vertical tail has a thick, wedge-shaped airfoil, and is distributed area-wise almost equally above and below the aft fuselage to assure adequate stability throughout the speed and altitude regime. The outer extremes of the verticals are all-movable, and the lower movable panel is jettisoned just prior to landing so that it would gain ground clearance with the rear landing gear extended. Speed brakes are located in the fixed portions of the upper and lower verticals. The side fairings on the fuselage contain the hydraulic, electrical, control, and fuel lines to avoid the problems of sealed passages through the center tank sections.

Subsystems

There are eight major subsystems in the X-15 research airplane. They are the engine, the propellant system, the hydraulic system, primary flight controls (aerodynamic), the ballistic control system, the auxiliary power system, the environmental control system, and the landing gear.

The basic propulsion unit to be used in the X-15 is the XLR-99 single-chamber rocket engine designed and built by the Reaction Motors Division of the Thiokol Corporation. It has a rated maximum thrust of over 50,000 lbs., and is throttleable from partial to full power. This engine will burn liquid oxygen and liquid anhydrous ammonia. It will be first installed in the third X-15. The first and second X-15 airplanes will each have two RMD XLR-11-5 rocket engines installed during initial flight test operations. These proven engines, one of which powered the X-1 research airplane, are placed one above the other in the aft fuselage of the X-15. These engines are not throttleable, as such, but can supply a thrust of from 2,000 lbs. to 16,000 lbs. by selective ignition of from one to eight of the rocket chambers of the dual configuration. The fuel used in these interim engines is liquid oxygen and alcohol. The XLR-99 and XLR-11 installations are interchangeable, and, ultimately, all three airplanes will have the -99 engine installed.

The propellant system has two main fuel tanks which are located in the center fuselage section. Helium gas is used for tank pressurization and fuel expulsion. The rate of fuel flow is in excess of 10,000 lbs. per min. It is interesting to compare this rate with that of a current operational fighter airplane, such as the F-100, which consumes 30,000 to 40,000 lbs. per hour. Decomposed hydrogen peroxide is used to drive the turbine-propelled pump which boosts the fuel and oxydizer up to engine manifold pressure.

The X-15 hydraulic system which powers the vertical and horizontal tail control surfaces, the speed brakes, and the landing flaps consists of two completely sepa-

rate 3,000 psi systems operating in parallel. This hydraulic system is driven by a new "piggy-back" combination of pumps, which receive power from the two APU units.

The primary flight controls are the moveable aerodynamic surfaces which are designed to operate with high surface loads, high load factor, and high operating temperatures. The X-15 does not have an automatic flight control system as such, but it does have hydraulic actuators with a damper system for stability augmentation about all three axes.

The ballistic control system is composed of small thrust units located in cruciform in the X-15 nose for pitch and yaw control and in the wing tips for roll. These control units use hydrogen peroxide jets for thrust. They will be used to control airplane attitude in the regions of flight where the air density is too low for the aerodynamic control surfaces to be effective. The pilot will move the ballistic control grip for desired airplane movement in the same manner as he would the aero-control grip. This system was designed and built by Bell Aircraft Corporation.

The twin auxiliary power units (APU) were made by General Electric. These units are driven by hydrogen peroxide fuel and operate in parallel. They supply the hydraulic and electric power for the various subsystems, instruments, and instrumentation.

The Garrett Corporation's AiResearch Division developed the environmental control system which supplies the pressurization and temperature control for the cockpit and equipment bay. Liquid nitrogen contained at −300°F. is vaporized to supply the necessary environment in these specially insulated areas. This system weighs 150 lbs. and has a cooling capacity of 27,000 B.t.u.

The mechanically operated landing gear consists of dual nose wheels and twin steel skids located in the aft fuselage. This gear is extended using gravity and the airstream for force. The use of a nose wheel is feasible because it is located in ready access to the favorable cockpit temperature environment, but to have wheels and brakes for the main gear would have required additional temperature protective environment in the aft fuselage with an associated and unnecessary weight penalty. Therefore, the use of steel skids on the main landing gear avoids creating additional protective environment and provides a natural braking force for deceleration during the landing ground run.

Materials and Structure

The selection of appropriate structural materials was based on isolated material strength characteristics at high temperatures, the availability of the material, and the relative predicted ease of fabrication, such as peculiar welding or forming properties. Skin gages were chosen to assure that required design temperatures were reached but not exceeded, and also to determine how built-up structure functioned at high operating temperatures. This also assisted in keeping the weight low. The thermal and flutter characteristics of the selected design was extensively proof-tested in thermal and aerodynamic wind tunnels.

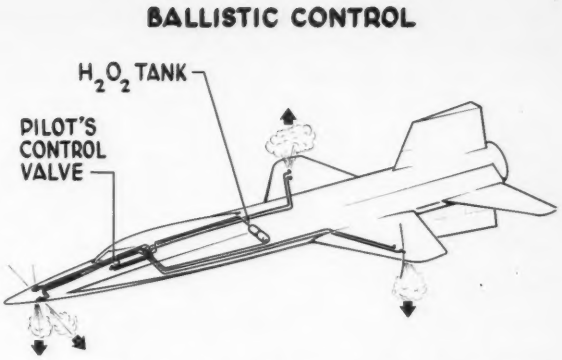

FIG. 2. Schematic sketch of the X-15 ballistic control system that will be used in space for attitude control since conventional aerodynamic controls will not be effective.

The temperatures to be encountered exceed 1,000°F. at the leading edges. These predicted peak temperatures together with the high temperatures on other portions of the airframe resulted in the selection of Inconel X, a nickel alloy steel developed by the International Nickel Company, as the material to be used on the entire outer surface of the X-15. The integral tank portion of the fuselage is subjected to internal temperatures of −300°F. caused by the liquid oxygen and external temperatures exceeding 500°F. caused by aerodynamic heating which occur simultaneously with high air loads at maneuvering load factors. The materials selected for most of the primary structure were titanium and stainless steel, with some aluminum used where heat and loads will not be excessive. The X-15 will be approximately 65 per cent welded together, whereas current operational aircraft are nearly 100 per cent fastened, using rivets, bolts, etc. This is a sign of the trend in fabrication techniques toward all-welded construction which will be used in many future airplanes. The forward fuselage containing the cockpit and equipment bay is of semimonoque construction as is the aft fuselage section which contains the power plant and supports the empennage. The center integral tank section of the fuselage is of monoque construction. The wings have an A-frame construction at the root section for tying into the wing-support frames which are an integral part of the tank structure, thus avoiding a carry-through spar which would complicate the tank construction. New welding techniques had to be developed, such as the use of evacuated, inert-gas-pressurized shields for welding titanium, to prevent weld contamination and loss of strength. The welding also required the development of new inspection techniques, such as the use of X-ray equipment. The program also featured the development of a brazed-sleeve tubing joint for the various plumbing lines to contain the hard-to-hold liquids and gases at extreme temperatures and pressures. The extreme operating conditions of pressure and temperature to be encountered required the search for and experimentation with

new plastics for bladders and seals, and also a new hydraulic fluid.

The necessary materials, techniques, and tolerances required in the fabrication of the three X-15 airplanes demanded the use of "hard" production-type tooling rather than "soft" prototype tooling. This is also a sign of what will be required for the production of the first few copies of future aircraft, even though the number of vehicles initially ordered may be small.

Instrumentation

The primary guidance equipment for the X-15 is an inertial flight data system using a three-gyro stable platform which will provide velocity, altitude, and attitude information. The data from this system developed by Sperry Gyroscope will be displayed on cockpit instruments as well as recorded for later analysis. In addition to this information, the pilot cockpit display will also include engine operating parameters, additional attitude reference with respect to the earth's surface from a three-axis indicator, developed by Lear, and instruments for monitoring the auxiliary equipment operation.

The flight test data, which will be recorded during the various missions, include pilot action, such as control movement; airplane response; and performance data, such as speed, altitude, acceleration. The X-15 has provisions for measuring and simultaneously recording approximately 600 temperatures, 140 pressures, and 65 strain-gage readings strategically located on the various surfaces and structure to obtain pressure and temperature distributions, heating rates, and structural load patterns. Approximately 90 channels of priority data will be telemetered to the three ground stations specially constructed for this program. The remainder will be recorded internally in the X-15. Photographic records of control surface movement and fuselage bending will also be made.

Pilot Gear

The pilot will wear a new full-pressure ventilated suit developed by the David Clark Company. This flight garment combines "G" protection with an environmental control system for ventilation, pressurization, and temperature, independent of the cockpit system. The suit's pressure feature is actuated if the cockpit pressure system fails. The suit also provides the pilot with adequate protection against the "wind blast" forces, the ambient temperature, and pressure conditions during ejection, should escape be necessary. The suit also supplies oxygen to the pilot.

The ejection seat is designed to protect the pilot against tumbling and flailing through stabilization devices and restraint. The seat will automatically separate from the pilot after adequate deceleration, and his parachute will deploy automatically.

Phases of Flight

The X-15 has been designed to perform a variety of missions in order to properly and completely evaluate the many factors of exit, space flight, and re-entry. Speeds of over 3,600 m.p.h. will be attained and altitudes of over 100 miles will be reached on various flights. The altitude and speed reached during a given mission trajectory will depend on the initial exit attitude assumed and the acceleration force applied. The pilot action required in the rarified air of the outer regions will include alignment of aircraft attitude, monitoring flight instruments, and establishment of desired aircraft attitude for re-entry. A typical mission is shown in the adjacent figure.

The X-15 is carried aloft under the right wing of a B-52 carrier airplane. The carrier will take off at Edwards AFB and fly to a position near Wendover, Utah, for the X-15 release for a maximum effort mission. This configuration requires that the X-15 pilot be in the cockpit from prior to carrier take-off until he lands the X-15 at the end of his mission—an elapsed time of approximately $2^1/_2$ hours. The pilot may escape from the X-15 by ejecting up over the B-52 wing, if necessary, while the research airplane is still attached to the carrier. Normally, recovery of both the X-15 and the carrier airplane will be Edwards AFB.

Space Flight in the X-15

Space may be considered to begin at altitudes of approximately 120,000 ft. for the speeds which are involved in the X-15 program. It is in this region that the aerodynamic controls will be ineffective due to the low dynamic pressures involved. The X-15 will allow the extension of human experience in a weightless condition by several times the length of time currently achieved in "pull-up–push-over" maneuvers in present day operational aircraft.

Under the present plan, the X-15 pilot will not be required to perform any special task procedure as part of a physiological or psychological study as such, but he will be monitoring his flight instruments and moving his control systems to maintain airplane attitude and control through the various stages of the mission since there is no autopilot.

One of the questions that is often asked is—will the pilot be more susceptible to vertigo under the weightless condition to be encountered at extreme altitudes? This is a controversial subject with positions on both sides of the argument. It is generally expected that he will have no more of a problem than on an instrument flight in today's current operational aircraft. Special protection against radiation effects has not been included for the pilot since opinion based on results of data gathered by balloon, missile, and satellite experiments does not deem it necessary, especially in view of the relatively short periods of exposure.

The air vehicle has been painted black to establish as high a rate of emissivity as possible for the dissipation of heat resulting from aerodynamic heating in order to reduce the heat absorption of the X-15 structure. Solar heating of the X-15 is expected to be of no consequence.

The airplane fuel spaces are filled with pressurized inert gas as fuel is consumed. The greatest fire danger exists at launch during engine light-up, but once lit, explosion is not likely. Once the fuel supply is spent, the danger of fire or explosion is essentially nil. However, in the event of control failure or air vehicle damage while at high speeds and extreme altitudes, the pilot will remain in the X-15 until it has descended to low enough altitudes and decelerated sufficiently to allow safe ejection. He would not be able to survive the re-entry forces and temperatures that the X-15 can tolerate. To eject in space would simply put him into a parallel trajectory and subject him to similar re-entry conditions as the airplane.

The X-15 will be tracked during the entire mission by radar at the ground stations of the test range and the pilot will be in continual radio contact with these stations. This monitoring together with the instrumentation assures a complete set of data for flight guidance, pilot safety, and flight analysis.

Conclusions

The objectives of the X-15 program are primarily concerned with the problems resulting from the flight conditions necessarily encountered during re-entry from space flight. It is for this reason that design emphasis has been placed on the air vehicle configuration, structure, materials, stability, and control requirements associated with the re-entry phase. These conditions must logically be proven to be satisfactorily solved before concentrating effort on manned space flight for extended periods of time, since any flight is programmed to ultimately terminate in re-entry into the earth's atmosphere.

The design and manufacture of the X-15 has required the development to a large degree of all the elements that are necessary for more extensive space travel. The flight test program will afford the verification of predicted characteristics and the correlation of this estimated and theoretical data with data gathered in actual flight.

The X-15 research program is a logical and necessary step in man's progress to understand and control the natural elements of his environment and adapt them to his use. No longer satisfied with the limits of his environmental elements within the earth's atmosphere, man is poised at the threshold of space, preparing to extend his realm of activity to the relatively unknown regions of outer space. The X-15 program is a giant-sized step in this direction.

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The Earth and Inertial Space *(Continued from page 36)*

where V_n, V_e, V_g and A_n, A_e, A_g are vehicle velocities and apparent accelerations in the earth's coordinates, north, east, and up, and Lt is the latitude of the vehicle. In the equations above, g is positive away from the earth. This shows there is a Coriolis effect in all three dimensions of the earth coordinate system.

Regardless of the direction of the vehicle's horizontal velocity, the Coriolis effect appears to be an acceleration to the right in the northern hemisphere and to the left in the southern.

A second Coriolis effect is apparent on a vehicle which has a significant change in altitude. A missile fired straight up would tend to maintain the original tangential velocity of the launch point. But to fall back to the launch point—an academic case—it should maintain instead the same *angular* velocity of the launch point. This effect of the Coriolis acceleration would make the missile lag the earth, or fall to the west of the launch point, as shown in Fig. 7.

The g component of Coriolis acceleration can be visualized by picturing a projectile fired due east, tangentially to the earth's surface. To an observer on earth, rotating toward the projectile, there would appear to be an upward force opposing gravity. An observer watching a projectile fired westward would be rotating away from the projectile and would therefore observe a force aiding gravity.

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(This article will be concluded in the May issue. Part II will discuss the shape of the earth and its effect on various parameters of interest to inertial navigation.)

" . . . to provide a unified survey of the fundamental theory of satellite orbits and to illustrate the theory, as much as possible, by numerical data presented in graphical form."

Satellite Orbit Mechanics

Harry Esses
Curtiss-Wright Corporation

RECENT DEVELOPMENTS in the technology of rocket vehicles, which have culminated in the successful launching of artificial earth satellites by both the Soviet Union and the United States, have stimulated considerable interest in orbital motion, particularly in those industries related to rocket development and its applications. In the community of scientists, interest is high because a skillfully instrumented satellite represents a valuable probe with which man can delve more deeply into the secrets of nature. The military, on the other hand, is concerned with possible applications of space vehicles in the development of new weapons systems. It is proposed, therefore, in this article to provide a unified survey of the fundamental theory of satellite orbits and to illustrate the theory, as much as possible, by numerical data presented in graphical form.

The Physical Model

In approximate calculations of satellite orbits, a convenient assumption, which does not depart seriously from reality, is that the earth is a sphere of homogeneous mass distribution. The problem of motion of a satellite around the earth is then reduced to that of one mass point (satellite) in the gravitational field of another fixed mass point (the earth). This model, however, is not an exact analog of the physical case because the earth is not perfectly spherical in shape but resembles an oblate spheroid. Nevertheless, if the object of interest is that of the general orbit configuration, the errors incurred by assuming a spherical earth can be ignored. For example, the principal effects of the oblate shape of the earth on the orbit of a satellite are: a regression or rotation of the plane of the orbit about the axis of the earth, and advance of perihelion or rotation of the orbit itself in its own plane. Dr. Whipple[1] has calculated a regression of 3.1° per day and an advance of perihelion of 0.4° per day for the orbit of Sputnik I, the world's first artificial earth satellite. Other effects that might be considered concern aerodynamic drag, orbit perturbations due to the gravitational field of the sun and moon, and the motion of the earth around the sun. Aerodynamic drag causes a decay in orbit size, a decrease in periodic time, and an increase in the satellite's orbital velocity.

The main effect of the field due to the sun on the satellite-earth system is to carry the system as a whole in an orbit about the sun. Moreover, since the mass of the earth is predominantly greater than that of the satellite, the center of mass of the satellite-earth system may be taken at the center of the earth, so the earth may be considered stationary relative to the satellite. In general, the effects mentioned are extremely important if it is desired to track the satellite point by point or to utilize perturbation data for scientific purposes but are relatively minor if one is concerned with the general properties of orbits. Readers who wish to pursue the topic of orbit perturbations further will find an excellent treatment of this problem in reference 2. In the remainder of this analysis, however, the assumption of a spherical earth will be accepted with the understanding that the theory to be developed is exact only for the idealized case involving point masses and spherically symmetric bodies.

Equations of Motion of the Orbit

Let the source point of an inverse-square, gravitational field* be located at a fixed point 0 (earth's

* This field is also referred to as an inverse-square, central force field, a Newtonian field, and a Kepler field.

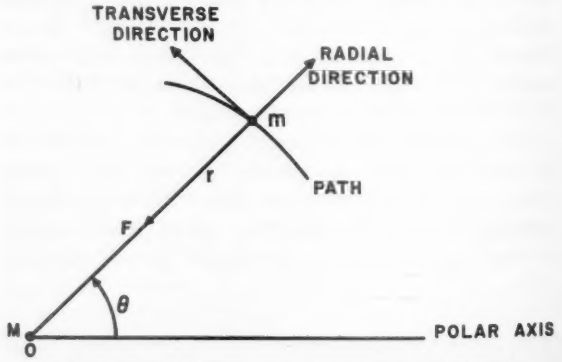

FIG. 1. Radial and transverse components of acceleration.

Harry Esses received his degree in physics and mathematics from Yeshiva University in 1955 and is engaged in postgraduate studies in mathematical physics at Columbia University. He taught physics at Stevens Institute of Technology and later, while in the Army, investigated attitude stability for cylindrical satellites at the Army Ballistic Missile Agency. Upon separation from the Army, Mr. Esses joined the Curtiss-Wright Corporation, Wright Aeronautical Division, as a Senior Engineer where he supervised orbital mechanics and space vehicle studies, ballistic missile trajectory analyses, and overall systems optimization for IRBM, ICBM, and space vehicles. The author is now a Senior Scientist in the Aerodynamics and Space Technology Division at General Applied Science Laboratories, Inc., Hempstead, N.Y.

center) and consider a single particle of mass m (satellite) moving relative to the fixed point. Since the velocity vector and the gravitational force vector always lie in a fixed plane, the trajectory of the particle is contained in a plane fixed relative to *inertial space*, and only two coordinates are required to specify the position of the particle relative to the fixed point 0. Introduce a system of polar coordinates with the pole coinciding with the source point at 0, and denote the position vector of the moving particle m relative to 0 by r, and the polar angle by θ (Fig. 1). Newton's Second Law of Motion can then be written in terms of polar coordinates, and the acceleration vector of the moving particle may be resolved into two components, one along the radius vector and one perpendicular to the radius vector. Since the gravitational force field is radial, the transverse component of acceleration is

$$(1/r)\ (d/dt)\ (r^2\dot{\theta}) = 0 \tag{1}$$

and the radial component is

$$\ddot{r} - r\dot{\theta}^2 = -(\mu/r^2) \tag{2}$$

where μ is a constant equal to $g_0R_0^2$, R_0 is the radius of the earth, g_0 the acceleration due to gravity at the earth's surface, and μ/r^2 the gravitational force per unit mass. As usual, the overhead dot denotes differentiation with respect to time. Eq. (1) can be integrated immediately to give

$$r^2(d\theta/dt) = h = \text{constant} \tag{3}$$

where h is recognized as the polar form for angular momentum per unit mass.

Referring to Fig. 2 it is clear that

$$dA = (1/2)r(rd\theta)$$

represents the element of area swept out by the radius vector r in a time dt. Thus the areal velocity is

$$dA/dt = (1/2)r^2(d\theta/dt) = h/2 = \text{constant} \tag{4}$$

Eq. (3) therefore contains two important results: the angular momentum per unit mass is constant; and the radius vector drawn from the source point to the particle sweeps out equal areas in equal times—this property is known as Kepler's Second Law. Eq. (2) can be solved for r by eliminating $\dot{\theta}$ and introducing the transformation

$$u = 1/r \tag{5}$$

By Eq. (3) and the differential identity

$$d/dt = (d/dy)\ (dy/dt) \tag{6}$$

Eq. (2) can be brought into the form

$$(d^2u/d\theta^2) + u = \mu/h^2 \tag{7}$$

This equation is the polar form for the differential equation describing the most general motion of a particle in an inverse-square, central force field. The general solution is

$$u = C\cos(\theta - \theta_0) + (\mu/h^2) \tag{8}$$

where C and θ_0 are constants of integration, and Eq. (8) is the equation of the trajectory of the particle relative to the fixed point 0. The arbitrary constant θ_0 may be eliminated by rotating the line $\theta = 0$ so that it coincides with the line θ_0. Then $\theta_0 = 0$ and Eq. (8) is

$$u = C\cos\theta + (\mu/h^2) \tag{9}$$

Since the gravitational field is conservative, the principle of conservation of energy may be used to evaluate the constant C.

The energy principle states that the sum of potential energy, U, and kinetic energy, T, of a particle moving in a conservative field is constant. This constant is the total energy E and may be expressed in polar coordinates, for a unit mass, by the relation

$$E = T + U = (1/2)\ (\dot{r}^2 + r^2\dot{\theta}^2) - (\mu/r)$$

Moreover, it follows from Eqs. (3), (5), and (6) that

$$\dot{r}^2 = h^2(du/d\theta)^2$$

Hence

$$(1/2)\ (\dot{r}^2 + r^2\dot{\theta}^2) = (1/2)h^2[(du/d\theta)^2 + u^2] = E - U = E + \mu u \tag{9a}$$

Inserting the expressions for u^2 and $(du/d\theta)^2$, obtained from Eq. (9), into Eq. (9a) gives

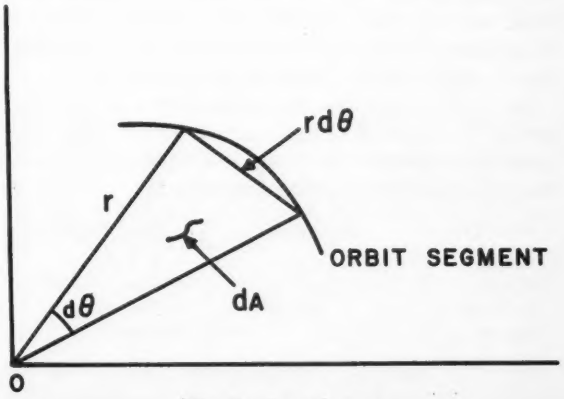

FIG. 2. Law of areas.

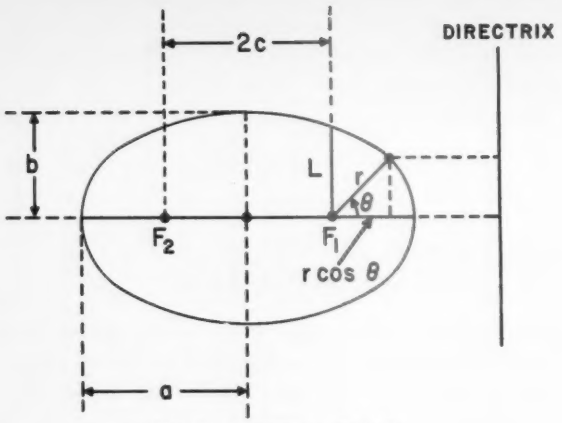

FIG. 3. Geometry of ellipse.

$$C^2 + (\mu^2/h^4) + (2\mu/h^2)C\cos\theta = (2E/h^2) + (2\mu^2/h^4) + (2\mu C\cos\theta/h^2)$$

and
$$C^2 = (2E/h^2) + (\mu^2/h^4) \tag{10}$$

which expresses the integration constant C in terms of the total energy per unit mass E and the angular momentum per unit mass h. Consequently, Eq. (9) may be written

$$r = (h^2/\mu)/[1 + \sqrt{1 + (2Eh^2/\mu^2)}\cos\theta] \tag{11}$$

The polar form for a conic section (Fig. 3) is well known to be

$$r = L/(1 + e\cos\theta) \tag{12}$$

where L is the semilatus rectum and e is the eccentricity of the orbit. A direct comparison of Eqs. (11) and (12) shows that the orbit is a plane conic section where

$$L = h^2/\mu \tag{13}$$

and
$$e = \sqrt{1 + (2Eh^2/\mu^2)} \tag{14}$$

General Properties of Orbits

The following important result, known as Kepler's First Law, has therefore been proved: relative to an inertial reference frame, the trajectory of a mass point moving in an inverse-square, central force field due to a fixed source point 0 is a plane conic section with the attracting point mass at one focus. Consequently, there are only four possible orbit types for a particle which moves in the gravitational field of a fixed point mass: ellipse; circle; parabola; and hyperbola.

Eq. (14) implies that the eccentricity e of the conic section is a function of the total energy E. The orbit types may therefore be classified in terms of the total energy according to the following scheme.

Orbit Type	Eccentricity, e	Total Energy, E
Ellipse	$e < 1$	$E < 0$
Circle	$e = 0$	$E = -(\mu^2/2h^2)$
Parabola	$e = 1$	$E = 0$
Hyperbola	$e > 1$	$E > 0$

Eq. (14) contains a considerable amount of interesting information, and a closer examination of it follows. Inasmuch as E represents the total energy of the particle, it consists of the sum of the kinetic and potential energy per unit mass, and is given by

$$E = (1/2)v^2 - (\mu/r) \tag{15}$$

where v is the velocity of the particle. Eq. (14) can therefore be written

$$e = \sqrt{1 + [(1/2)v^2 - (\mu/r)]\,(2h^2/\mu)} \tag{16}$$

The four cases listed above will be discussed in terms of Eq. (16).

Parabolic Case

The condition $E = 0$ corresponds to an eccentricity of unity and is represented geometrically by a parabola. Moreover, the requirement $E = 0$ implies that:

$$v = \sqrt{2\mu/r} \tag{17}$$

Since the eccentricity of a parabolic trajectory is unity, the parabola lies at the transition point between the closed elliptical path $e < 1$ and the hyperbolic path $e > 1$. Insofar as a parabola is an open geometrical curve, a body moving with a speed given by Eq. (17) would traverse a parabolic trajectory and "escape" into infinite space.

The velocity defined by Eq. (17) is the so-called "escape-velocity" or parabolic velocity, and at the surface of the earth has a value of about 36,700 ft./sec. It might be observed that since eccentricity is a function of a single parameter, the total energy E, it follows that the escape velocity is independent of the launching direction.

Hyperbolic Case

The condition $E > 1$ corresponds to eccentricities greater than unity and is represented geometrically by a family of hyperbolas of different eccentricities. This requires that

$$v > \sqrt{2\mu/r} \tag{18}$$

or velocities exceeding the escape-velocity. Consequently, a body moving with a speed given by Eq. (18) would escape from the earth along an hyperbolic path. Note that bodies traversing hyperbolic paths possess more energy than the minimum required for escape from the earth, and, therefore, the velocity of the body "at infinity" will be greater than zero, in contrast with the parabolic case.

Elliptical Case

The condition $E < 0$ corresponds to eccentricities less than unity and is represented geometrically by a family of ellipses of various eccentricities. Of the three types of conic curves, the only closed orbit is the elliptical orbit—the circular orbit may be considered a special case of the elliptical orbit. Since the elliptical orbit corresponds to the case $e < 1$ or $E < 0$, it follows that *the total energy is always negative for a closed orbit*

The negative sign is due to the convention of defining the zero level of potential at infinity.

Circular Case

The condition

$$E = -(\mu^2/2h^2) \tag{19}$$

corresponds to an eccentricity of zero and is represented geometrically by a circle. The required velocity for a circular orbit is found by inserting the value for E, given by Eq. (15), into Eq. (19), and observing that a necessary condition for a circular orbit is that the velocity vector be perpendicular to the radius vector to the particle. For this case, the angular momentum per unit mass is

$$h = rv \sin(\pi/2) = rv$$

so that substituting for E and h in Eq. (19) gives

$$v = \sqrt{\mu/r} \tag{20}$$

Note that the circular orbital velocity given by Eq. (20) differs from the escape velocity [Eq. (17)] only by a factor of $\sqrt{2}$. It is to be noted further that for any given r there is a unique parabolic and a unique circular velocity. This is due to the fact that each of these curves is defined by an equality ($e = 1$, $e = 0$) rather than by inequalities as in the case of elliptical ($e < 1$) and hyperbolic ($e > 1$) orbits. Fig. 4 illustrates how the elliptical orbit becomes increasingly eccentric, and ultimately transforms into a parabolic, then hyperbolic orbit, as the initial launching velocity is progressively increased.

It should be observed that lunar and interplanetary missions may be accomplished by traversing elliptical, parabolic, or hyperbolic trajectories. Until high thrust rocket engines are developed, however, these missions will probably be restricted to trajectories in the form of elongated or "transfer-ellipses" because minimal energy is required for flight paths of this type. For such "transfer-ellipses" the perigee point will be close to the earth and the apogee point will be near the target body (moon, planets). The Air Force's Pioneer Moon Rocket, for example, was programmed for a trajectory of this type.

It might be noted further that, although greater energy is required for orbits of the parabolic and hyperbolic type, mission flight time is considerably reduced for such trajectories.

Properties of Elliptical Orbits

One of the most important of the various types of orbit is the elliptical orbit. The more important properties and terminology associated with the elliptical orbit are presented below.

The parameters which determine the characteristics of the elliptical orbit may be divided into geometrical parameters and dynamical parameters.

Geometrical Parameters

It follows from analytical geometry that the geometrical parameters are related as follows:

$$L = b^2/a = a(1 - e^2) \tag{21}$$

$$e = c/a = \sqrt{(a^2 - b^2)}/a < 1 \text{ (definition of ellipse)} \tag{22}$$

where a and b denote the semimajor and semiminor axes, respectively, and c is one-half the distance between the two focuses.

The polar form of the equation for a conic section, which represents an ellipse if $e < 1$, is given by Eq. (12). It follows that from Eqs. (21) and (12)

$$r = [a(1 + e)(1 - e)]/(1 + e\cos\theta) \tag{23}$$

Moreover, Eq. (23) implies that for $\theta = 0$, r is minimum, and for $\theta = \pi$, r is maximum. Consequently, the minimum and maximum focal radii are given by

$$r_p = a(1 - e) = \text{perigee} \tag{24}$$

$$r_a = a(1 + e) = \text{apogee} \tag{25}$$

Eqs. (24)–(25) furnish expressions for perigee and apogee in terms of the semimajor axis and the eccentricity. Inversely, the semimajor axis and eccentricity can be determined if the perigee and apogee are specified. A glance at Eqs. (21)–(25) shows that all of the geometrical properties of the ellipse* are determined if any *two* of its independent parameters are given.

Relations Between the Geometrical and Dynamical Parameters

The dynamical parameters may be taken as the total energy per unit mass and the angular momentum per unit mass. Various important relations connecting the geometrical and dynamical parameters are derived below. Combining Eqs. (21), (13), and (14) gives

$$a = -(\mu/2E) \quad \text{or} \quad E = -(\mu/2a) \tag{26}$$

It is noted that the semimajor axis a depends on a single parameter, the total energy, so that *all orbits of the same total energy have the same semimajor axis.* Inversely, it follows that *all orbits of the same semimajor axis have the same total energy.* Moreover, Eq. (26) implies that the total energy increases (becomes less negative) inversely as the semimajor axis.

Orbital Velocity

The velocity of a satellite at any point in its orbit may be obtained by combining Eqs. (26) and (15). The result is

$$v = \sqrt{\mu[(2/r) - (1/a)]} \tag{27}$$

Eq. (27) indicates that the velocity varies inversely with r. The maximum velocity occurs for minimum r (perigee) and the minimum velocity occurs at maximum r (apogee). Hence, from Eqs. (24) and (25) the velocities at perigee and apogee are:

$$v_p = \sqrt{(\mu/a)\,[(1 + e)/(1 - e)]} \tag{28}$$

$$v_a = \sqrt{(\mu/a)\,[(1 - e)/(1 + e)]} \tag{29}$$

An interesting relation implied by Eqs. (24)–(25)

* Outside of its orientation in space.

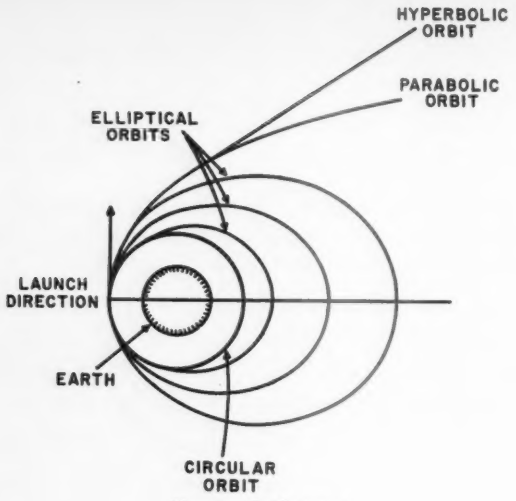

FIG. 4. Orbit types.

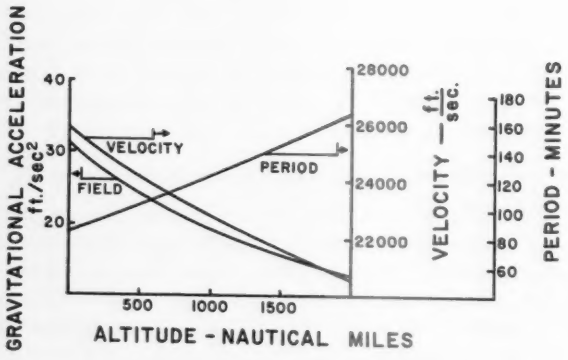

FIG. 5. Variation of velocity, period, and field, with altitude for circular orbits.

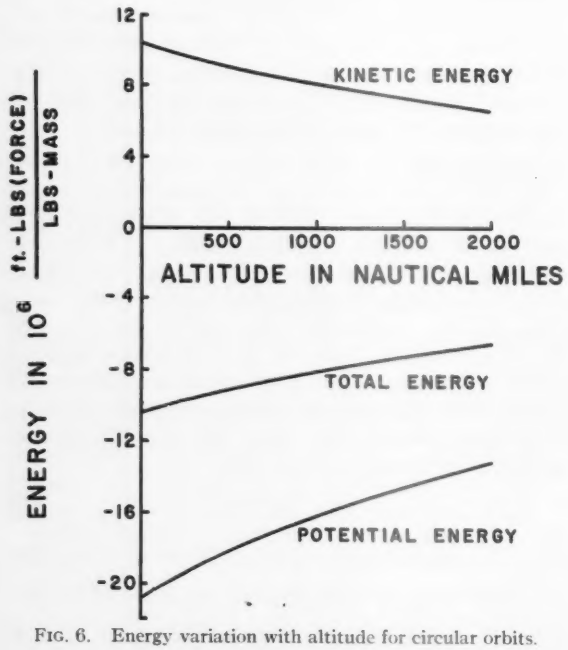

FIG. 6. Energy variation with altitude for circular orbits.

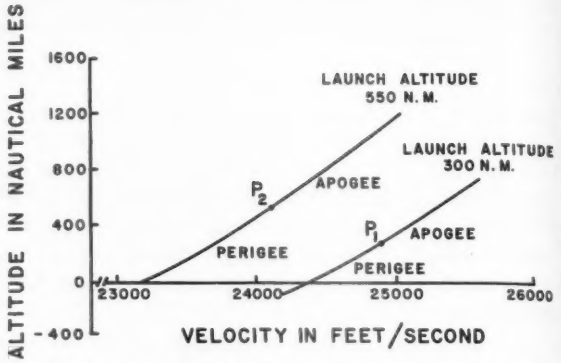

FIG. 7. Apogee and perigee as a function of launching velocity for zero launch angle.

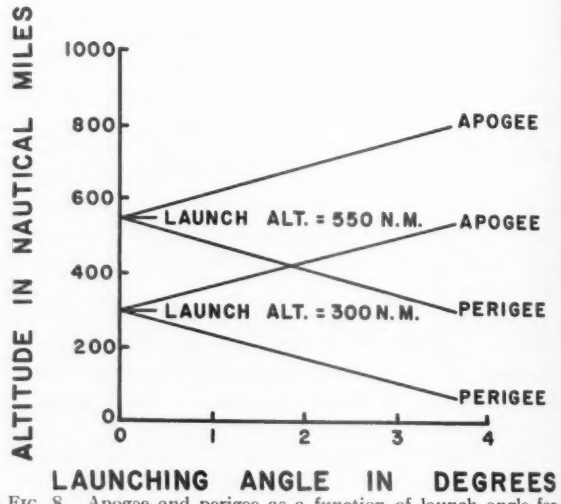

FIG. 8. Apogee and perigee as a function of launch angle for circular launch velocity and fixed altitude.

TABLE - I
COMPARISON OF OBSERVED AND COMPUTED VALUES OF PERIODIC TIME

	SPUTNIK I	EXPLORER I	VANGUARD I	
Apogee Earth's Surface (n.m.)	486 ---	1377 ----	2140 ----	Observed Calculated
Perigee Earth's Surface (n.m)	126 ---	190 ---	351 ---	Observed Calculated
Semi-Major Axis (n.m.)	3743 ----	4221 ----	4683 ----	Observed Calculated
Period (minutes)	96.2 95	114.5 114	134 133	Observed Calculated

and (28)–(29) is

$$v_p r_p = v_a r_a \tag{30}$$

which states that the velocity at perigee times the perigee radius is equal to the velocity at apogee times the apogee radius.

The Periodic Time

The time required for a satellite to complete one revolution around the earth is called the period. From the Law of Areas [Eq. (4)], it follows that

$$dA = (1/2)h\,dt$$

Integrating this equation around the entire ellipse gives

$$A = \oint (1/2)h\,dt = (1/2)h\,\tau$$

where τ is the period. The area A of an ellipse is given by $A = \pi ab$. Hence,

$$\tau = (2\pi ab/h)$$

Substituting for b from Eq. (22) and noting from Eqs. (13) and (21) that the angular momentum is

$$h = \sqrt{a\mu(1 - e^2)}$$

gives the following expression for the period

$$\tau = 2\pi a^{3/2}/\mu^{1/2} \text{ or } \tau = 2\pi\mu/(-2E)^{3/2} \tag{31}$$

Eq. (31), known as Kepler's Third Law, implies that the period depends on only one geometrical parameter, the semimajor axis, or on only one dynamical parameter, the total energy.

Consequently, *all orbits of the same total energy have the same period*, and all orbits of *the same period have the same semimajor axis or the same total energy*.

A glance at the above equations shows that all the orbit characteristics are completely determined if any two independent geometrical or dynamical parameters are specified.

Illustrations for Parameters of Elliptical Orbits

The characteristics of circular and elliptical orbits are examined in this section as a function of altitude, launch velocity, and launch angle. A set of figures is furnished to illustrate the theory developed and to provide an idea of the orders of magnitude of relevant quantities.

(a) The variation of velocity, period, and gravitational field is shown in Fig. 5 as a function of altitude for circular orbits. It is seen that the velocity and field decrease with altitude, whereas the periodic time increases with altitude.

(b) The variation of kinetic, potential, and total energy per unit mass, with altitude, is shown in Fig. 6 for circular orbits. It is seen that the kinetic energy decreases with altitude, whereas the potential and total energy, both of which are negative, increase with altitude.

(c) The variation of apogee and perigee as a function of velocity is shown in Fig. 7 for a given fixed launch altitude and zero launch angle (angle between the velocity vector and horizontal). Two launching altitudes, 300 and 550 n miles, are represented. If the launching velocity equals the circular velocity, then perigee and apogee are equal and the orbit is a circle. These points are denoted by P_1 and P_2. As the launch velocity increases to values exceeding the circular velocity, the launching altitude (perigee) remains constant and the apogee moves further and further from the surface of the earth. Thus, all points of the curve above P_1 and P_2 represent apogee points for given perigee. However, for velocities less than the circular velocity, the launching altitude represents the apogee, and points on the curve below P_1 and P_2 are perigee points for a fixed apogee. Points for which the altitude is less than zero represent velocities for which the elliptical orbit intersects the earth.

(d) Apogee and perigee are shown in Fig. 8 as a function of launching angle for a fixed launching altitude and circular velocity. It can be seen that for a given launch velocity and altitude, the apogee increases with an increase in launch angle, while the perigee decreases with increasing launch angle.

(e) To indicate the degree of accuracy obtainable on the basis of the theory developed in this article, a comparison of observed and calculated values for the initial periods of the orbits of Sputnik I, Explorer I, and Vanguard I are shown in Table 1.

Insofar as periodic time is a function of the semimajor axis alone, the period of each orbit listed in Table 1 may be read directly from Fig. 5 by selecting the circular orbit with a radius equal to the semimajor axis of the ellipse in question.

Relativistic Satellite Experiment

Although Einstein's Special Theory of Relativity has received considerable experimental verification, there has been to date relatively slight experimental support for his Generalized Theory (Theory of Gravitation). With the advent of artificial earth satellites, it has become possible to test experimentally at least one aspect of the Generalized Relativity Theory.

One implication of the theory is that a "clock" located in a strong gravitational field should run at a slower rate than a "clock" of identical construction located in a weak gravitational field. For example, a "clock" on the sun should run more slowly than a similar "clock" on the earth. In addition, it is known from Special Relativity that the rate of a "clock" is a function of its velocity. The rate of a "clock" moving in a gravitational field will thus be a function of both its speed and position in the field. It is clear that a "clock" located in an earth satellite should experience both these effects, so that it is possible to measure these effects experimentally. In describing the results expected from an experiment of this type, it will be assumed for simplicity that the satellite moves in a circular orbit. [Elliptical orbits may be treated by substituting Eq. (27) for Eq. (20) in the following discussion.] Let a "clock" located in the satellite trans-

mit signals to the earth at periodic time intervals—e.g., each second. An observer on the earth recording the time interval between two received signals would find that a time interval dt, noted with respect to an earth "clock," had elapsed between the two signals, where the time dt is given by[3]

$$dt = d\tau/\sqrt{1 + (2\phi/c^2) - (v^2/c^2)} \qquad (32)$$

Here $d\tau$ is the time interval between signals, as recorded by an observer on the satellite; ϕ is the potential difference between the satellite and the earth, as noted by an earth observer; v is the velocity of the satellite relative to the earth, and c is the velocity of light. The potential difference ϕ is

$$\phi = \mu[(1/R_0) - (1/r)]$$

and the velocity of the satellite is given by Eq. (20). Consequently, Eq. (32) can be written

$$dt = d\tau/\sqrt{1 + \mu/c^2[(2/R_0) - (3/r)]} \qquad (33)$$

It is therefore noted that (a) at altitudes below 2,000 miles the satellite "clock" runs more slowly than the earth "clock"; (b) at $r = 3/2\ R_0$, or at an altitude of about 2,000 miles, both "clocks" run at the same rate; and (c) at altitudes exceeding 2,000 miles the satellite "clock" runs faster than the earth "clock."

The order of magnitude of this effect is $\sim 10^{-10}$ and can be detected by "atomic clocks."* It should be observed that although the mentioned effect is small, its significance is not. Detailed considerations on the experimental procedures connected with experiments of this type can be found in reference 4.

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[3] Møller, C., *The Theory of Relativity;* Clarendon Press, Oxford, England, 1952.

[4] Singer, S. F., *Applications of an Artificial Satellite to the Measurement of General Relativistic "Red-Shift,"* Phys. Rev., Vol. 104, No. 1, October 1, 1956.

* In an actual experiment one observes a "frequency shift" in a vibrating source (atom). The velocity effect manifests itself as a Doppler shift, and the effect of the potential field is exhibited as a gravitational frequency shift. The total frequency shift is the superposition of the Doppler and gravitational frequency shifts.

✦ ✦ ✦

National Space Program (Continued from page 33)

the Russians. The contest, although ideologically centered, covers a very wide front of human endeavor. The space aspects, however important, are but a part of this total contest. Any national and effective space planning must reflect this proper perspective.

It is my observation that a national blueprint for the attainment of space goals and for a fair share of space leadership—one that properly utilizes our established capability, that implies and provides for the incorporation of the results of extensive applied research, and that reflects the true scope of the international issues—is not yet sufficiently clear.

If the nation is to secure positive and lasting benefits from its investment in space, this blueprint must be clearly drawn up and continuously updated. Our space purposes must be defined, and national management responsibilities refined and sharply focused.

In addition to the foregoing, we must have—and the need will become greater as the total contest becomes greater—an enlightened and enlightening leadership, one whose decisions will be made wisely and who recognizes the need for our people to understand the wisdom of such decisions. With an understanding of the requirements, reasons, and decisions of the space program itself, I am sure all of us will measure up to the needs of the program, no matter how difficult they may be.

It is my belief that, as steadily as the barriers were overcome that beset the early progress of the United States ballistic missile program, there will, as surely, emerge a sound United States program for the exploration of space.

✦ ✦ ✦

The Growing Problems in the Space Program (Continued from page 42)

turers to push ahead, but the scientific race has become a prestige race, particularly with Russia. Clearly, there are no governors on such a program; the competitor can call the tune. Here, possibly more than at any other place, a program which is international in scope or at least bilateral between the United States and the Soviet Union might be one of the finest things that could be done, first, for the sake of a sensible program in space, second, for the sake of a balanced program with respect to other fields of science.*

* The unclassified data in this paper were taken largely from the *Space Handbook: Astronautics and its Applications*, Staff Report of the Select Committee on Astronautics and Space Exploration, prepared by the RAND Corporation, Santa Monica, Calif.

Unique problems related to environment, performance, reliability, and application are illustrated by an example based on a Mars probe.

Electronic and Communications Aspects of Space Flight

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THE ABILITY to perform experiments with unattended instrumentation aboard deep space vehicles operating at great distances from the earth will clearly be dependent on the ability to communicate reliably with these vehicles. In the design of communication equipment for space vehicles, one will perhaps be compelled to make some unusual design compromises; however, the means for attempting to meet communications requirements will still be found in applying fundamental principles of communication to radically new conditions and environments. Of prime importance in these new conditions and environments will be two basic factors mentioned initially—namely, the requirement to operate unattended for long times and to operate over extreme communication ranges. These requirements are typically exemplified by an example involving a Mars probe.

In designing a Mars probe, one, obviously, would like to arrange that the vehicle arrives at Mars near opposition time—that is, at the time when the distance between the earth and Mars is at a minimum. The opposition distance, however, varies. It has a minimum of about 30 million nautical miles and a maximum of about 55 million nautical miles. For the opposition, which will occur on December 30, 1960, the minimum distance is about 49 million nautical miles. However, there are some practical problems in selection of transfer orbits which will not always enable us to communicate over these distances. Some examples of these trajectory requirements are given in Table 1. From this, we see that it will be quite costly to try to meet Mars very near opposition time for the opposition of 1960 (it would take a velocity of about 48,000 ft./sec. to arrive at opposition), remembering that payload carried by a rocket vehicle decreases quite rapidly as the required burnout velocity is increased. If one tries simultaneously to minimize communication distance and transit time, which governs the unattended time in the transfer orbit, rather small payloads can result. On the other hand, if one tries to maximize the payload, extreme communication distances can, in many cases, result. Therefore, in general, one will have to make some compromise which results in adequate payloads without exceeding achievable communication ranges. Instead of being able to communicate at opposition distances, one may, in general, have to plan for communication at distances perhaps two to three times as great as opposition distances.

TABLE 1
Sample Trajectory Parameters for 1960 Mars Probe

	Launch date (1960)	Arrival date (1961)	Velocity required, ft./sec.	Earth-Mars distance at arrival date, million nautical miles
	August 24	February 6	43,700	60
	September 15	February 15	40,600	66
	October 3	March 1	37,700	74
	October 15	March 15	38,800	87
	November 3	April 8	40,400	110
Launch at node	November 10	March 10	43,200	83
	November 10	May 10	40,600	132
	November 10	July 10	39,000	162

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Bruno W. Augenstein is a Consultant to the Chief Scientist's staff in Lockheed's Missiles and Space Division. In addition to the authorship of many classified publications, he has contributed to the IAS *Journal of the Aero/Space Sciences* and other similar volumes. A member of several professional societies, he became affiliated with Lockheed in 1958 after nine years with the RAND Corp.

Fundamental System Parameters

At the disposal of the designer's choice are two parameters of basic importance in the communication link; the choice of frequency and the choice of bandwidth. If we consider the case of a radio link with one terminal at the earth's surface, then frequencies below at least 10 mc. can be ruled out because of reflection effects of the earth's ionosphere, and frequencies above about 30,000 mc. are generally unsuitable because of atmospheric attenuation by oxygen and water vapor. On the basis of these propagation loss considerations alone, one can restrict the design to frequencies between about 10 and 30,000 mc. Within this frequency range there may be other constraints if ionospheric propagation considerations are taken into account, since dispersion and faraday effects decrease as the square of the frequency for the worst case, and attenuation and deviations decrease as some function of frequency. Solar noise, cosmic noise, and man-made interference will also decrease fairly rapidly as frequency is increased. These factors, therefore, indicate a requirement for use of a rather high frequency.

On the other hand, factors such as transmitter efficiency and receiver noise figure would, in general, push us toward lower frequencies. Similarly, many of the largest receiving antennas become less efficient at very high frequencies due to constructional deviations. Therefore, a compromise is indicated in which we use a frequency just high enough to minimize solar noise, cosmic noise, and man-made interference, as well as ionospheric propagation effects, but not so high that transmitter efficiency and antenna construction become limiting or receiver noise figure becomes limiting.

These considerations indicated that a suitable range of frequencies might be from 500 mc. to about 2,000 mc. This frequency range choice is also suitable from the standpoint of using existing ground installations. For example, many of the antennas used in radio astronomy have been designed to pick up the emission from interstellar neutral hydrogen at a frequency of about 1,400 mc. If we design our transmitter to operate not much higher than this frequency of 1,400 mc., we will be able to make maximum use of these existing installations.

A list of large antennas used in radio astronomy is given in Table 2, together with some of the pertinent operating characteristics.

Large antennas of this kind are especially suitable for space communication because they are generally precision antennas and have already been emplaced to avoid man-made interference to as great an extent as possible. Furthermore, these existing radio astronomy antennas have a reasonably suitable geographical distribution, though not an ideal one, for communicating with a deep space probe as nearly continuously as possible, and we would, therefore, find it desirable to utilize antennas of this character as the ground terminal of our communications link. There are, of course, in existence also a number of large military antennas.

TABLE 2
Radio Observatory Large Antennas

	Location	Size, ft.	Frequency mc.
(1)	Jodrell Bank University of Manchester, England	250	1400
(2)	Dwingleloo, Netherlands	84	1400
(3)	Millstone Hill, Mass. Lincoln Lab	84	3000
(4)	Green Bank, W. Va. National Radio Observatory	140	10,000
(5)	Harvard Harvard Observatory	60	3000
(6)	Naval Research Laboratory	50	24,000
(7)	Naval Research Laboratory	84	3000
(8)	Ann Arbor, Mich. University of Michigan	84	10,000
(9)	White Lake, Canada Dominion Observatory	84	1400
(10)	Big Pine, Calif. Owens Valley Observatory	84	1500
(11)	Goldstone, Calif. Jet Propulsion Lab	84	3000
(12)	Stanford, Calif. Stanford Research Institute	60	600
(13)	College, Alaska University of Alaska	60	600
(14)	Hawaii Space Technology Lab (Pioneer Site)	60	3000
(15)	Sydney, Australia Radiophysics Laboratory	200	3000

The choice of bandwidth is also governed by several conflicting requirements. First of all, we want to minimize the noise level in the communication system. For many types of system noise, one can regard the noise power as being proportional to the bandwidth, if the channel bandwidth is small compared with the carrier frequency. Types of system noise which behave in this way are internal receiver noise, solar and cosmic noise, and some types of man-made interference. Some other noise sources—such as certain types of distortion due to the atmosphere—exist which do not fall into this category, and the effect of these noise sources would be treated separately. In general, however, the requirement for keeping the noise power to as low a level as possible—thereby also reducing the received signal power required for a given signal-to-noise ratio—would imply that we use as small a bandwidth as possible.

On the other hand, the capacity to transmit information also decreases as the bandwidth is decreased. This can be inferred from the fundamental equation of information theory:

$$C = W \log_2 [1 + (S/N)] \qquad (1)$$

where C is the information transmitting capacity of a communication channel in bits per sec., W is the channel bandwidth in cycles per sec., S equals the average received signal power, and N equals the average noise power. We see that, for a given signal-to-noise ratio, the information transmitting capacity of the channel decreases directly as the bandwidth is decreased.

The required transmitting channel capacity, of course, depends on the application. Two specific applications are of interest in a space vehicle. The first of these is the determination of the vehicle position,

which is required to search for and to track the vehicle. The second important requirement is the telemetering of scientific data. The required channel capacity in this case depends upon the number of different types of data to be telemetered, the desired accuracy of the readings, and the desired data sampling rate. The following example illustrates a possible situation: Suppose it were desired to measure a quantity to an accuracy of one part in a hundred, and to take a reading every second; with the measured quantity actually varying significantly in 1 sec., the required channel capacity then would be the logarithm to the base two of a hundred, or about $6^1/_2$ bits per sec.

In general, for extreme communication path links these two conflicting requirements—namely, the desire for high tracking accuracy and high information transmitting capacity which will increase the required bandwidth, and the wish to cut down the required radiated power which decreases when the bandwidth decreases—will be dominated at the present time by the latter situation; namely, the requirement to decrease the radiated power, and to accept the reduced tracking accuracy and the reduced channel capacity for transmitting scientific data.

For illustrative purposes, we will use a bandwidth of one cycle per sec. and assume the use of phase locked tracking filters to permit a successful recovery of information in this extremely narrow bandwidth. To establish the required power output from our probe vehicle, we use the assumptions listed in Table 3. These assumptions are presently realizable or reasonable extrapolations of the present state of the art. The values in this table are obtained in the following way. The theoretical receiver noise, or Johnson noise, for this receiver at a bandwidth of one cycle per sec. will be minus 204 dbw. Maximum sensitivity for the receiver will be given by:

$$-204 + \text{N.F.} + S/N + \text{Losses} = -187 \text{ dbw} \quad (2)$$

Free space attenuation α can be expressed as follows:

$$\alpha = 38 + 20 \log f + 20 \log R - G_r - P_t \quad (3)$$

where f equals operating frequency in mc., R equals distance in nautical miles, G_r equals antenna gain in db., and P_t equals power output in dbw. G_r can be eliminated in terms of the operating frequency and the diameter, D, of the antenna in ft., and the result:

$$P_t = -96 + 20 \log R - 20 \log D \quad (4)$$

gives the required power output in dbw. (decibel watts) as a function of the distance in nautical miles for the communication path, and the antenna diameter in ft.

TABLE 3
Communications Range, Nautical Miles, as a function of Radiated Power, Watts, and Receiving Antenna Size, ft.

	Radiated power		
	30 dbw. (1000 watts)	20 dbw. (100 watts)	10 dbw. (10 watts)
Receiving antenna: 84-ft. parabola	170×10^5 miles	52×10^6 miles	17×10^6 miles
Receiving antenna: 250-ft. parabola	470×10^6 miles	150×10^6 miles	47×10^6 miles

Assumptions:
(1) Receiver noise figure = 3 db. (temperature = 300°K)
(2) Losses = 2 db.
(3) Signal/noise ratio = 12 db.
(4) Receiver bandwidth = 1 cycle per sec.
(5) Omnidirectional vehicle antenna
(6) 55 per cent efficiency of receiving antenna

The theoretical capacity for transmitting information, as given by Eq. (1), is about $3^1/_2$ bits per sec. for this system. However, to avoid possibly excessive complexity in the encoding process in order to approach this theoretical information capacity, an actual capacity using relatively simple encoding schemes perhaps would be closer to one bit per sec. Consequently, it would take about 7 sec. for this communication system to transmit a piece of telemetered data with a measurement accuracy of one part in a hundred. Similarly, range accuracy can be calculated, assuming on-off AM keying, and assuming that the pulse rise time can be preserved to a reasonable tolerance to indicate that a range accuracy of plus or minus 10,000 miles might be achievable at extreme communication distances.

Instrumentation

Deep space probes, of which the Mars probe is an example, will enable us to do much new basic research in astronomy, astrophysics, and planetary geophysics. The instrumentation for such basic research is well

TABLE 4
Space Science Measurements

Near earth (<10^6 miles)	Between planetary orbits	Near Mars
Trapped radiation Shielded and unshielded counters Telescope plus magnetic and solar aspect indicators	Solar wind detectors and solar aspect indicators (indication to be compared with simultaneous measurements near earth)	Camera and readout equipment (10^4 to 2×10^6 miles)
Magnetic field Total field Hydromagnetic waves	Magnetometer (indications to be compared with simultaneous measurements near earth)	Infrared spectra (10^4 to 2×10^6 miles)
Cosmic radiation (low energy heavy primaries)	Micrometeorites	Magnetism (1) Total field (2) Hydromagnetic waves
Micrometeorites	Interplanetary gas	Trapped radiation (<10^5 miles)
Mass spectrometer or other form of ion detector	Vehicle temperature	Mass spectra (<10^3 miles)
Checkout of photographic equipment	Solar nebula	
Checkout of infrared spectrometer	Cosmic ray spectral distribution and total flux	

TABLE 5
Primary Power Sources

	Energy ratio: Low discharge rate	Energy ratio: High discharge rate	Lifetime
Silver peroxide zinc battery	70 wh./lb. (10 hr. rate)	15 wh./lb. (10 min. rate)	Two weeks (activated)
H_2-O_2 fuel cell	250 wh./lb.	*	6–12 mo.
Solar cells	8.5** w./lb.	*	1–2 yr.
Nickel-Cadmium secondary battery	17 wh./lb. (6 hr. rate)	10 wh./lb. (10 min. rate)	20 yr. or 7000 charge–discharge cycles

* Requires secondary battery for peak discharge rates.
** Plane array normal to sun near earth.

known, so that fairly specific experiments can be planned for. Some of these experiments have been tabulated in Table 4. These experiments have been broken down into three categories, some to be executed while the vehicle is in its exit phase from the earth-moon system, a second while the vehicle is in interplanetary space between planetary orbits, and a third when the vehicle nears another planet. These three categories of experiments may be performed either by different vehicles or by single vehicles over the entire transfer orbit when the payload of the vehicle is adequate.

Auxiliary Power Sources

Table 5 lists some of the various sources of electrical power for the instrumentation and communication link of a typical space vehicle.

The power supply closest to being an off-the-shelf item is an electrochemical system or battery. Included in the table is the performance of a few selected battery systems. It is worth noting that the performance of a battery system depends rather sensitively on its drain rate. Furthermore, chemical batteries are also handicapped if we require them to operate at low ambient temperatures, but, fortunately, it appears possible to design probe vehicles so as to maintain a suitable internal environment for the batteries.

Solar cells have been flown in the Vanguard vehicle, and, apparently, operate quite well. Possible hazards of the solar cells include the impingement of micrometeorites, which might have an effect similar to sandblasting. While we now have some indications of micrometeorite impingement results on satellites near the earth, we have, as yet, no firm data on the density of micrometeorites in interplanetary space. Furthermore, laboratory experiments in high-speed impact phenomena have not yet clarified the extent of damage to be expected when impacts do occur. It is worth noting that, while the radiation flux from the sun in the vicinity of Mars is considerably less than that near the earth, the solar cells would also operate at lower temperature near Mars. These two effects would, to some extent, tend to compensate, since solar cells work more efficiently at lower temperatures. As indicated in the table, to achieve maximum drain rates from an auxiliary power system involving solar cells, it is necessary to include a secondary battery to provide the high-peak power drains of short duration, such as those which would be involved in the transmission of data.

Complete Probe Experiment Packages

So far, we have discussed individually the communications requirements, instrumentation for possible experiments, and auxiliary power sources. We can now try to assemble these components into a complete probe experiment package, matching the power requirements for communication purposes and instrumentation purposes with the power output of the auxiliary power source. A typical weight and power breakdown of such a complete probe experiment package is shown in Table 6.

The probe used is a relatively simple one in which experiments are flown which can be used both in interplanetary space and near Mars. The instrumentation, therefore, is assumed to be functioning continuously. The probe vehicle is assumed to be unstabilized. This has two primary effects.

First, we will generally need an omnidirectional antenna on the vehicle itself, and, second, the vehicle will have to be essentially surrounded by solar cells so that adequate auxiliary power is available, irrespective of the vehicle's actual orientation. The weights and powers shown for the instrumentation, the on-board data processing, the communication equipment, and the auxiliary power source are intended to be realistic and, in some cases, conservative values. While weight

TABLE 6
Possible Probe Equipment List (Unstabilized Probe)

Equipment	Weight, lbs.	Power requirements: Watts peak	Power requirements: Watts continuous	Power requirements: Watt-hr. per day
Sensors	25			
Micrometeorite	1		0.011	0.26
Magnetic field	7		10	240
Radiation	12		5	120
Grid mass spectrometer	3		1	24
Wiring	2			
On-Board data handling (Encoder, tape recorder, timer, wiring)	28			485
Communications	87			
Transmitter*	25	250		125
Power supply	40	60		30
Modulator	10	10		5
Receiver	5	10		10
Antenna	2			
Wiring and installation	5			
Auxiliary power supply	108			
Solar cell banks	42			
Secondary battery	30	170		85
Inverter	21	85		45
Cell erection and support	10			
Wiring and installation	5			
Total weight, instrumentation and communications package–248 lbs.				
Total power, watt-hr. per day				1170

* 100 watts radiated power

and power reductions could, undoubtedly, be effected for many of the components shown, the values used are intended to represent gear of high reliability.

The actual weight of the instrumentation flown is a relatively small fraction of the total weight, and the majority of the weight is devoted to the communications part of the circuit and to the auxiliary power supply. This is simply illustrative of the fact that it is the actual communication with the vehicle and the transmission of data, not simply the experiment to be performed, which place the greatest strain on the design of the probe system. The communication system in the table radiates the power of 100 watts from the vehicle, and the total readout time for transmitting of data is 30 minutes per day. During this time, the system discussed can transmit 1,800 or more bits of information, or the equivalent of about 250 two-place numbers.

Possible Further Improvements

As is evident from the discussions and assumptions of the previous four sections, there are many places where significant improvements may be made in the feasibility of communicating over extremely long communication path links. One such possibility is simply to use a directional antenna on the vehicle. This implies that the vehicle must be stabilized about two or three axes, or possibly that the antenna itself is oriented by some external reference. In addition to permitting use of directional antennas on board the vehicle, stabilization systems also permit us to point the solar cell banks always at the sun, thus additionally reducing the required cell bank weight. The total weight of the stabilized systems, even including the weight required to effect stabilization, appears to be very considerably below that of the unstabilized system. However, one must consider against this the possible accompanying decrease in system reliability through the use of the stabilization system.

Further increases in range or reductions in overall power requirements for a given channel capacity can be made by improvements to many other components as well. For example, the use of masers or parametric amplifiers will allow substantial decreases in the noise figure of receivers. The use of such devices will emphasize the existence of losses in the antenna and transmission line which are low enough so that their effects are usually masked by the relatively high noise input of ordinary receivers. If this excessive input noise does not exist, the antenna system can limit the performance. In order to take full advantage of these and similar low-noise devices, it will, therefore, be necessary to do extensive work to improve antennas and transmission lines. Similar improvements are in sight in the design of more efficient transmitters, in advances in message coding, and the use of highly efficient data recovery methods.

Improvements are also possible in the primary power sources. It appears, for example, that the efficiency of the electrochemical cell can be considerably improved over that currently available, and some work is done in this direction. Work is also in progress on the use of nuclear reactors as primary power sources, as well as the use of isotope heat sources; thermoelectric generators are also being investigated for the production of power. The relative advantage of nuclear primary power sources or isotope primary power sources compared with the present solar cell banks depends relatively sensitively on the specific application involved. It appears at the present that if long duration, very high power levels are required (on the order of several kw. or more), the nuclear or isotope power sources may have some advantages. On the other hand, for power levels of several hundred watts, the solar power source, especially on a stabilized vehicle, is in a relatively favorable position and will, undoubtedly, continue to be used for a great many applications not involving excessive distances from the sun.

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This paper discusses three-dimensional trajectories of nonlifting bodies in satellite orbits, taking into account such geophysical factors as the gravitational field due to the oblateness of the earth, the nonspherical figure of the earth, and the rotation of the earth's atmosphere. The main emphasis is on the re-entry phase of the trajectories.

Three-Dimensional Satellite Orbits

With Emphasis on Re-Entry Dynamics and Oblateness Effects

Jack N. Nielsen, AFIAS

Vidya Associates

Atmospheric Phases in Two-Dimensional Satellite Orbits*

AS LONG AS atmospheric drag is negligible, an earth satellite of negligible mass compared to the mass of the earth moves around the earth in a Keplerian ellipse with the center of the earth as a focus. The drag is greatest at the point of closest approach to the earth—that is, at perigee. The air drag reduces the total energy of a satellite in a way that can be quite accurately calculated for a known orbit, provided that the air density and the satellite drag coefficient are known. The loss of energy per revolution can be thought of as causing the satellite to drop into an elliptical orbit of lower energy level. In so doing, the satellite gains one unit of kinetic energy and loses two units of potential energy. This behavior explains the apparent paradox that the satellite speeds up as the result of drag. This approach has been used by such authors as Henry[2] to calculate the lifetime of satellites.

The orbit resulting from the action of drag on a Keplerian path is shown in Fig. 1 where it is referred to as "circularization of the ellipse." As a result of the drag, the perigee altitude decreases less rapidly than the apogee altitude. The elliptical path thus approaches a circular shape. When the change in shape of the elliptical orbit per revolution is small, it is possible to study the change in shape as a continuous function of the number of revolutions.

After the ellipse is circularized, the trajectory enters a phase known as spiral decay. In this phase the radius from the center of the earth to the satellite is a monotonically decreasing function of time. As the satellite loses altitude, it will after a time slow down rather than speed up. The satellite will turn from an almost horizontal trajectory to an almost vertical one as the altitude further decreases. This phase is called the terminal phase, and it extends to impact at the surface of the earth if the satellite does not destroy itself by burning. It should be noted that not all of the foregoing phases necessarily occur in a given trajectory.

Particular attention will be paid to the terminal phase of the trajectory since the maximum acceleration and heat transfer occur in this phase. Special dynamical analyses applicable to this part of the trajectory have been made by such authors as Chapman,[3] Allen and Eggers,[4] and Gazley.[5]

Geophysical Factors Influencing Satellite Forces

The geophysical factors which can significantly influence the trajectories of earth satellites include the atmosphere of the earth, the nonspherical figure of the earth, and the gravitational field of the earth including its oblateness component. The nonspherical figure of the earth refers solely to its geometric shape. The oblateness component of the gravitational field is due to the mass distribution of the earth which is not spherically symmetric partly because of the nonspherical figure of the earth and partly because of its nonuniform density distribution.

Atmosphere of the Earth

The influence of the atmosphere of the earth on the satellite trajectory is through air drag. (We neglect lift here.) For the purposes of this paper it is assumed that the density is a unique function of altitude measured above the surface of the earth. For the lower portion of the atmosphere, below 200 km., the ARDC atmosphere[6] is used for this function. Above about 200 km., the recent observations on Sputnik I, 1957 α_2, have shown that the air density may be as much as an order of magnitude greater than previously supposed.

* The detailed mathematical treatment of the material presented is to be found for the most part in NASA Memo. 12-4-58A by Nielsen, Goodwin, and Mersman.[1] This reference represents an attempt to compute complete re-entry trajectories on an IBM 650 computing machine as accurately as possible.

After graduation from the University of California in 1941, Dr. Nielsen became an employee of NACA, continuing there until 1958, except for duty with the 188th Engr. Combat Battalion and for graduate work at Caltech to obtain his doctorate. He is an author of about 35 technical papers, mostly NACA publications, covering a wide range of aeronautical subjects. He is also the author of a forthcoming book on missile aerodynamics. Dr. Nielsen, together with Wallace Davis, Morris Rubesin, Jackson Stalder, and Prof. Karl Spangenberg, founded Vidya in Palo Alto, Calif., last June to combine the disciplines of aeronautics, thermodynamics, and electronics.

Precise calculation for the lifetime of earth satellites requires more accurate knowledge of upper air densities than now available. One of the principal assumptions regarding air density is that it depends only on altitude and is independent of latitude, time of day, and season. This assumption is retained in lieu of systematic data on these variables. For the calculations of this paper the altitude is always less than 200 km.

Figure of the Earth

By the figure of the earth, we mean the geometric shape of the earth or the geoid. The geoid is the shape the earth is defined to have. A number of geoids have been defined[7] in the shape of oblate spheroids with the polar axis as the axis of rotation. For the purpose of this study the geoid is that defined by the International Geodetic and Geophysical Union of 1924. The equatorial radius is defined to be 6,378,388 ± 18 m., with the polar radius taken to be shorter than the equatorial radius by precisely the 1/297th part of the equatorial radius. The polar radius then turns out to be about 13 miles shorter than the equatorial radius.

The influence of the nonspherical figure of the earth on the satellite trajectory is through the mechanism of air drag. Assume a satellite orbit of perfectly circular form in a plane through the poles. On the equator the satellite will be 13 miles closer to the earth than at the poles. For such a change in altitude the density changes about eightfold. It is clear that the frequent assumption of a spherical earth is unwarranted if accurate satellite trajectories are desired. For nonequatorial orbits the nonspherical figure of the earth should be taken into account in any but the most approximate solutions.

Gravitational Field

The gravitational field of the earth can be broken down into a part with spherical symmetry and a nonspherical part. The part with spherical symmetry has a potential which describes the usual inverse square law of gravitation.

$$\phi_s = KM/r$$

where

ϕ_s = potential of spherically symmetrical field
K = universal gravitational constant
M = mass of earth
r = radius from center of earth

The product KM is known to six significant figures from astronautical observations. The nonspherical part of the gravitational potential ϕ_0 has components inversely proportional to r^3, r^5, etc. The part proportional to r^{-3} is the dominant component and is generally agreed to have the following form:

$$\phi_0 = -(KM/r)\ (\mu a^2/r^2)\ (1 - 3\cos 2\psi)$$

where

6μ = $(1.637 \pm 0.004)\ 10^{-3}$
a = equatorial radius of earth
ψ = geocentric latitude (Fig. 2)

The constant μ is an experimentally determined constant which gives the strength of the oblateness gravitational field. The potential is that for two doublets which closely approach each other, as shown in Fig. 2.

The components of the gravitational force field are found by taking the derivatives of the potential in the direction of the component. The oblateness gravitational field thus has radial and tangential components. The radial component at the equator acts to increase the gravitational attraction because of the equatorial bulge. At the poles the oblateness effect acts to re-

FIG. 1. Atmospheric phases in satellite re-entry.

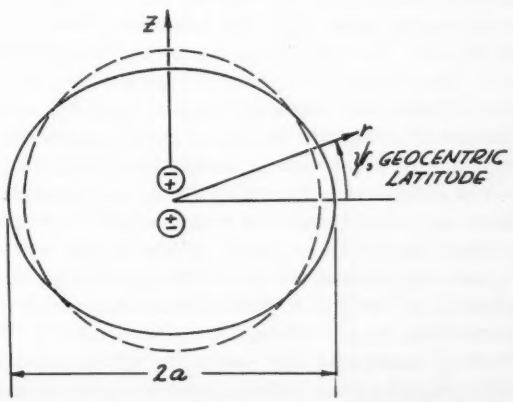

FIG. 2. Construction of oblateness gravitational potential.

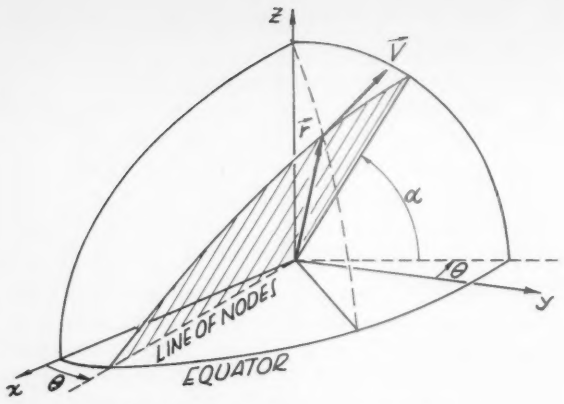

FIG. 3. Inertial coordinates and orbital plane.

duce the gravitational attraction. It is to be noted that the tangential components act always to pull the satellite toward the equator.

At about 75 miles altitude, the oblateness and aerodynamic drag forces are of the same order of magnitude for W/C_DA of about 30, where W = weight of satellite, C_D = drag coefficient, and A = reference area.

Equations of Motion

Coordinate Systems

Care must be taken in the choice of a coordinate system if an efficient solution to a satellite trajectory problem is desired. It is desirable to have a reference inertial coordinate system for deriving the equations of motion. A system of axes fixed in direction but moving with the earth would be an inertial system, except for the centripetal acceleration of the system due to the motion of the earth around the sun and for precession and nutation of the polar axis. However, for the purposes of this paper such effects are very small, and we can take our inertial system as a set of Cartesian axes, one axis coincident with the polar axis, moving parallel to itself at all times.

Such an inertial system of axes is shown in Fig. 3 as the x y z system. Consider a satellite with radius vector $\vec{r}$ and vector velocity $\vec{V}$. The vectors $\vec{r}$ and $\vec{V}$ define a plane called the orbital plane. The intersection of this plane with the equatorial plane is the line of nodes, the node shown here being the ascending node. Two angles are required to specify the position of the orbital plane, the angle θ specifying the position of the line of nodes and the angle α specifying the tilt of the plane. It is interesting to note that the principal effect of oblateness is to cause a change in the angle θ. Oblateness causes the line of nodes to move or regress backward against the directed motion of the satellite at a rate proportional to cos α. The maximum rate of regression of the line of nodes for a near satellite is about 0.6 deg. per revolution.

Having established the coordinate system and the orbital plane, let us consider a more detailed version of the previous figure as shown in Fig. 4. Note that in addition to θ and α, we have the radius r and polar angle ϕ in the orbital plane. The unit vectors $\vec{i}_r$, $\vec{i}_\phi$, and $\vec{i}_\alpha$ define a coordinate system centered on the satellite in terms of which equations of motion will be given. We also have another pair of coordinates λ and ψ which form a quasi-geographic system. The first coordinate λ is the absolute longitude of the satellite measured from a fixed direction in space. The quantity ψ is the geocentric latitude, being an angle in a system of spherical polar coordinates. It differs slightly from the geographic latitude used in cartography which is defined from a spirit level reference that includes gravitational and earth rotational effects.

Consider the number of dependent variables in the dynamics of the system which depends on time as the independent variable. Besides the angles θ and α defining the position of the orbital plane, there are the polar coordinates r and ϕ defining the position of the satellite in the orbital plane. Finally, there are the two components of the vector velocity $\vec{V}$ which by definition lies in the orbital plane. We thus have six dependent variables—four of position and two of velocity.

Newtonian Equations of Motion

We will give the equations of motion in the r, ϕ, and α system without proof, as taken from reference 1. Let F_r, F_ϕ, and F_α be the components of the forces of drag and gravitation (including oblateness effects) acting, respectively, in the $\vec{i}_r$, $\vec{i}_\phi$, and $\vec{i}_\alpha$ directions. Also, let V_ϕ be the horizontal component of the satellite velocity. Then the equations of motion have the following simple form:

$$\ddot{r} - (V_\phi^2/r) = F_r/m$$

$$\dot{V}_\phi + (\dot{r}/r)V_\phi = F_\phi/m$$

$$V_\phi \Omega_r = F_\alpha/m$$

subject to the kinematic relationships

$$\dot{\phi} + \dot{\theta} \cos \alpha = V_\phi/r$$

$$\dot{\alpha}/\cos \phi = \dot{\theta} \sin \alpha/\sin \phi = \Omega_r$$

The first three equations are the equivalent of four

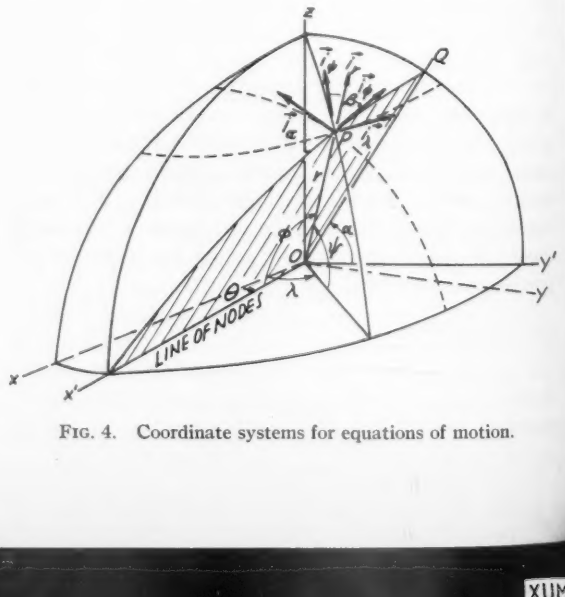

FIG. 4. Coordinate systems for equations of motion.

first-order equations. These, taken together with the second set of two first-order equations, yield a total of six first-order equations. This number equals the number of dependent variables, as it should.

Elliptic Orbital Elements

The preceding equations of motion can be integrated numerically step by step to yield a trajectory. However, for many purposes it is better to change to a set of dependent variables which are representative of the ellipses which fit various segments of the satellite trajectory. The dependent variables of such a set are termed elliptic orbital elements, and there are a large number of independent sets of six. Without drag or oblateness, the satellite orbit is a perfect ellipse. Introducing drag and oblateness should cause only small deviations from this ellipse as long as we avoid the terminal phase. This fact forms the obvious basis of a perturbation method, in which small departures from a basic ellipse are calculated. Another perturbation method is that of variation of parameters. In this method we determine the variation with time of the parameters characterizing the ellipses which instantaneously match the trajectory at every point. These parameters are the orbital elements.

Consider the instantaneous dynamical state of a satellite. This state is determined by the radius vector $\vec{r}$ and the vector velocity $\vec{V}$. If there is no drag or oblateness, these vectors specify a unique ellipse which is the orbit. The parameters defining this unique ellipse are equally representative of the instantaneous dynamical state, and their time histories fully specify the trajectory when drag and oblateness are present.

To specify one particular set of orbital elements, consider Fig. 5. This figure shows the ellipse which a satellite with vectors $\vec{r}$ and $\vec{V}$ would follow for no drag or oblateness.

The polar form of the equation for this ellipse is

$$1/r = [1 + E \cos(\phi - \delta)]/[l(1 - E^2)]$$

where

l = semimajor axis
E = eccentricity of ellipse
δ = position of perigee
ϕ = polar angle

Taking these four parameters, together with the angles θ and α specifying the orbital plane, we have a set of six orbital elements. Time will then be the independent variable. If we were interested in how things changed per revolution, we might let the polar angle ϕ be the independent variable and let time be a dependent variable.

It is clear that many sets of orbital elements can be constructed. Some other parameters which could be used are kinetic energy, momentum, semiminor axis, *latus rectum*, etc. A set different from the above is used in reference 1. Still another set is given in reference 8, and is reproduced by Taratynova in reference 9.

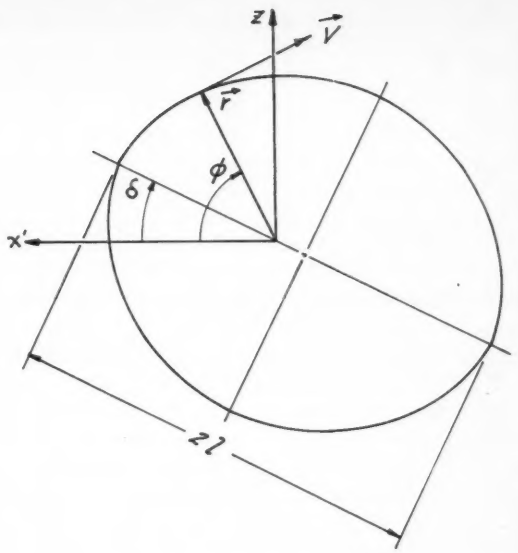

FIG. 5. Instantaneous ellipse.

One advantage of the formulation of the equations of motion in terms of orbital elements is the direct physical significance gained thereby. Another advantage is that the orbital elements are usually slow-varying functions of time so that numerical integration of the equations of motion can be made using large time intervals. One disadvantage of the particular set used in reference 1 is that certain of the elements become quite large as impact is approached so that the numerical integration is ill conditioned.

Calculative Example Using Orbital Elements

As a first numerical example, let us examine the results of an application of the equations of motion in terms of orbital elements to an equatorial orbit with and without the oblateness gravitational field. For the calculation, the product of the drag coefficient and the frontal area divided by the mass $(C_D A/m)$ was taken to be unity. This value is representative of a manned re-entry vehicle. The initial orbit is taken circular at 120 miles altitude with a horizontal velocity corresponding to circular orbital speed neglecting oblateness

$$V_c = (KM/r)^{1/2}$$

For the calculation without oblateness, the drag was "turned on" at time zero when the eccentricity is zero. The satellite then enters a spiral decay phase and starts to lose altitude. The resulting trajectory was calculated on an IBM 650 computer with a sufficiently small interval size to ensure an accurate trajectory. For the oblateness calculation, the drag and the oblateness gravitational field were both "turned on" at time zero. The gravitational attraction was thereby suddenly increased for the equatorial orbit used in the calculation. The oblateness trajectory was also calculated on an IBM 650 computer. Compari-

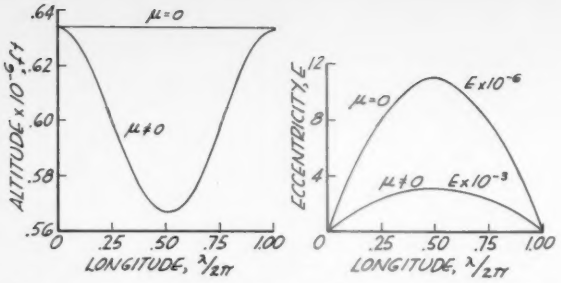

FIG. 6. Effect of oblateness on periodic variations of satellite in equatorial orbit.

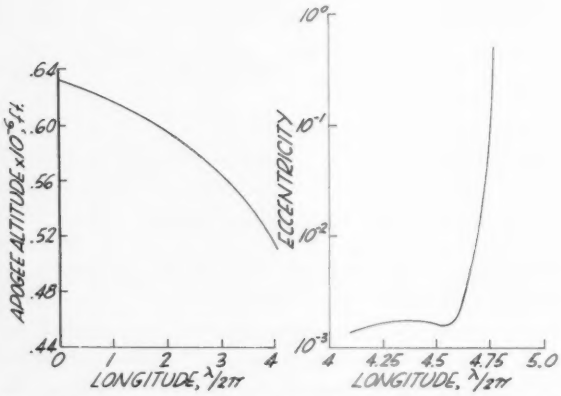

FIG. 7. Secular trends during terminal phase of satellite in equatorial orbit.

son of the two trajectories shows the perturbations of the trajectory due to the oblateness gravitational field. In both calculations atmospheric rotation has been included. It is assumed that the atmosphere rotates uniformly with the angular velocity of the earth.

Periodic Variations

In the discussion of the effects of oblateness we distinguish between periodic variations and secular trends. The periodic variations are fluctuations during a cycle which do not accumulate from cycle to cycle. The variations which do accumulate are termed secular trends. The effects of oblateness on periodic variations are illustrated in Fig. 6 where the altitude and eccentricity are plotted against the longitude of the satellite for one revolution. With drag but no oblateness, the satellite loses altitude monotonically and enters a spiral decay phase. The nominal eccentricity becomes of the order 10^{-5} as the result of drag, and the satellite loses about 800 ft. altitude per revolution. This loss of altitude is too small to register in Fig. 6. With oblateness, the satellite goes into an orbit of greater eccentricity, of the order 10^{-3}, with well-defined perigee and apogee. In fact, the altitude difference between apogee and perigee is of the order 70,000 ft. For an explanation of the appearance of an apogee point at time zero, first note that, when the oblateness field is included, the gravitational attraction in the equatorial plane is increased. A satellite in an equilibrium circular orbit for no oblateness thus has a velocity deficiency to maintain a circular orbit if the gravitational attraction is suddenly increased at time zero. Since the radial velocity was taken as zero at time zero, we must have apogee or perigee, but, since the satellite speed is too small to maintain a circular orbit, the initial point must be an apogee point.

Because the altitude of the satellite is generally lower with oblateness than without it, the calculated average drag of the satellite over the cycle is approximately doubled. As a result, the satellite loses altitude at about twice the rate with oblateness than without it.

Secular Trends

The secular trends are illustrated in Fig. 7 for the terminal phase of the trajectory. The value of C_DA/m for this figure is 10 rather than unity so that impact would occur from 120 miles altitude in a few revolutions. The altitude at apogee is plotted versus the number of revolutions together with the eccentricity. This satellite completes four revolutions but comes to impact before completion of the fifth. The variation of the eccentricity is interesting. It remains of the order 10^{-3} until impact is approached, at which time it quickly rises to unity. It can be shown that the eccentricity of the instantaneous ellipse is given by

$$E^2 = 1 - 2[1 - (V^2/2V_c^2)]\,(V_\phi^2/V_c^2)$$

where

V = satellite speed
V_ϕ = horizontal component of V
V_c = circular orbital speed

If the horizontal velocity becomes zero, the eccentricity becomes unity.

The present calculations never reached impact because the independent variable ϕ used in the calculation becomes constant if the flight path becomes vertical. One way to overcome this difficulty is to switch to time as the independent variable. However, among the orbital elements used in the calculations, several became large as the path became vertical. This ill-conditioning was not removed for the impact calculations, but rather the method of orbital elements was abandoned in favor of a quasi-geographic method.

Quasi-Geographic Formulation of Equations of Motion

A particular set of coordinates suited to calculation of trajectories to impact is a quasi-geographic system based on radius, latitude, and longitude. With reference to Fig. 5, these quantities are denoted r, λ, and ψ. As previously mentioned, the latitude is a geocentric quantity, and the longitude is measured from a fixed direction in space rather than from Greenwich. In terms of the new coordinates, the equations of motion are essentially those for spherical polar coordinates.

$$\ddot{r} - r\dot{\psi}^2 - r\dot{\lambda}^2 \cos^2 \psi = F_r/m$$

$$[1/(r \cos \psi)]\,(d/dt)\,(r^2 \cos^2 \psi \dot{\lambda}) = F_\lambda/m$$

$$r\ddot{\psi} + 2\dot{r}\dot{\psi} + r\dot{\lambda}^2 \sin \psi \cos \psi = F_\psi/m$$

The forces per unit mass including drag and oblateness forces are easy to write down.

Calculative Example Involving Quasi-Geographical Coordinates

In this example let us consider a nonequatorial orbit, with the orbital plane inclined at 65° to the equator. Also, let the initial altitude at the equator be 80 miles so that the satellite comes to earth in about a revolution with C_DA/m of unity. The satellite is moving horizontally at circular orbital speed over the equator at time zero. Over the range for which the calculations using orbital elements are accurate, the trajectories as calculated by orbital elements and by the quasi-geographic method were in agreement. Atmospheric rotation is included.

General Aspects of Three-Dimensional Orbits

It is of interest to note certain aspects of three-dimensional orbits as illustrated in Fig. 8 in which latitude, longitude, and altitude are plotted versus time. The magnitudes of the maxima and minima in latitude are equal to the inclination of the orbital plane to the equator. The longitude increases steadily with time. The altitude-time curve is of interest since it shows the altitude initially increasing. Actually the nonspherical figure of the earth causes this effect since the orbit is almost nearly circular. The first maximum in the altitude corresponds closely to maximum north latitude of the orbit. As the satellite crosses the equator heading south, there is a second minimum in the altitude.

The satellite moves along its λ, ψ trajectory relatively uninfluenced by drag. While its λ, ψ coordinates do not depend much on C_DA/m, its altitude does. In this connection, inclusion of the oblateness gravitational field has an effect on altitude qualitatively similar to increasing C_DA/m. When the satellite descends to a certain altitude dependent on C_DA/m, it starts its re-entry. Thereafter it loses its horizontal velocity rapidly through a combination of downward curvature and deceleration due to drag. It pulls out of its general trajectory and descends nearly vertically. Ticks are placed on the λ and ψ curves at this point. The corresponding ticks on the altitude curves show that the satellite has penetrated deep into the atmosphere before this behavior occurs.

Impact Point

One thing clear from Fig. 9 is the large influence that oblateness can have on range and the location of impact. In fact, for the present example, inclusion of oblateness forces reduced the range about 6,000 miles. Thus, by neglecting oblateness gravitational forces, a manned re-entry vehicle attempting to circumnavigate the globe and land in Washington, D.C., could well end up in the middle of the Pacific.

Atmospheric rotation has a large influence on impact point although not so large as that of the oblateness gravitational field. Two distinct effects can be differentiated. First, for a satellite launched in the direction of the earth's rotation, the rotation of the atmosphere tends to reduce the drag of the satellite by a few per cent. The satellite will follow the same general λ, ψ trajectory as without earth rotation but at a somewhat higher altitude. It thus travels farther before it pulls out of the main trajectory. The longitude difference due to this effect is about 1,200 miles. The second effect occurs during that part of the trajectory when the satellite has decelerated substantially to subsonic speeds. If there were not atmospheric rotation, then the satellite would come in almost radially as viewed by an observer in the inertial framework. But with atmospheric rotation, the satellite is pulled along with the earth and appears to descend vertically as seen by an observer on the earth. Since the earth moves eastward at a maximum rate of about 1,000 m.p.h. and the satellite is in approximately vertical flight for about 300 sec. (for C_DA/m of unity), the maximum change in impact point is about 80 miles in longitude. The first effect is thus the overriding one.

Importance of Various Terms in Equations of Motion During Re-Entry

The re-entry phase of a manned re-entry vehicle is of particular importance since maximum heating and

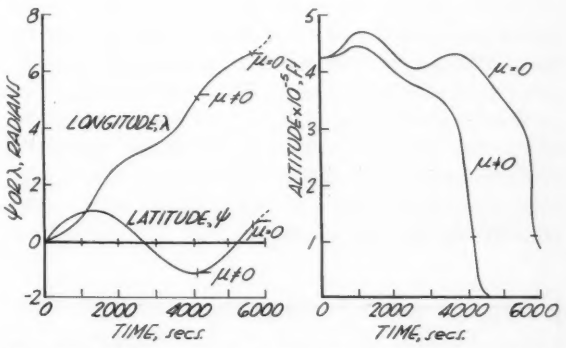

FIG. 8. General features of three-dimensional nonequatorial trajectories.

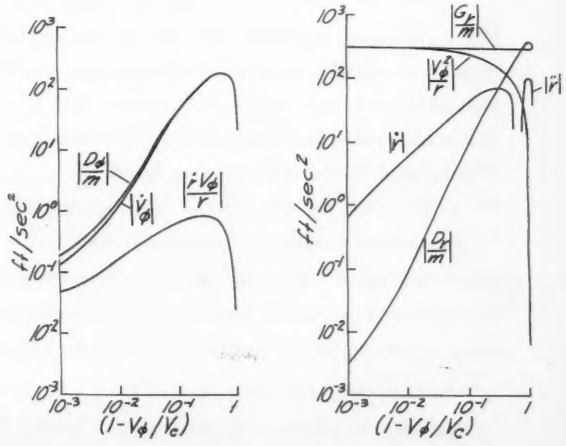

FIG. 9. Magnitudes of terms in equations of motion.

maximum acceleration occur in this phase. It is thus of interest to examine the terms in the equations of motion for this phase to obtain physical insight into re-entry dynamics. To this end, the quasi-geographic method was applied to the precise calculation of an equatorial orbit to impact and the magnitude of the various terms in the equations of motion thus determined. The equations of motion in question are

$$\ddot{r} - (V_\phi^2/r) = (D_r/m) + (G_r/m) \qquad \text{radial motion}$$

$$\dot{V}_\phi + (\dot{r}/r)V_\phi = (D_\phi/m) + (G_\phi/m) \qquad \text{horizontal motion}$$

where

(D_r/m), (D_ϕ/m) = components of drag per unit mass in radial and horizontal directions, respectively

(G_r/m), (G_ϕ/m) = components of gravitational field in radial and horizontal directions, respectively

The magnitudes of the various terms are shown in Fig. 9 for re-entry from a circular equatorial orbit at 80 miles altitude with C_DA/m of unity. The magnitudes are plotted against the quantity $1 - V_\phi/V_c$ to facilitate the presentation. The quantity V_ϕ/V_c is a characteristic number of significance in the study of the various regions of the re-entry phase.

Examining first the magnitude of the various terms in the tangential equation of motion, we note that the horizontal drag component and the tangential acceleration dominate the motion. The acceleration of gravity in the horizontal direction, G_ϕ/m, is due entirely to oblateness. It is negligibly small for many engineering purposes and is not included in the figure. The acceleration component $\dot{r}V_\phi/r$ is also negligible for satellite re-entry, at least for speeds less than 99.9 per cent of circular satellite speed. This assumption is the basis of the Z-function method of Chapman.[3]

The equation of radial motion contains terms of the orders of magnitude shown in Fig. 9. For values of satellite speed near circular orbital speed, the gravitational attraction G_r/m is balanced by the centrifugal force V_ϕ^2/r. Near the end of the trajectory the motion is largely vertical, and the gravitational attraction and drag force dominate the motion. However, the radial acceleration must still be taken into account if accurate results are desired. For the entire trajectory an analytical solution is not yet at hand. The numerical solutions of Chapman, however, are very useful for most engineering purposes.

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"When solutions are accomplished, it is believed that an engine system will be available which, while it cannot be of use without the chemical rocket, will supplement the chemical rocket for space flight."

Ion Rocket Engine Systems—A Summary

Robert H. Boden, AIAS
North American Aviation, Inc.

MANY FACTORS have stimulated increasing interest in the development of high-performance thrust generators for space vehicles. Among these are recent developments in large chemical rocket engines and new high-performance power plants, increased knowledge of the physics of particles, the recent successes both in this country and in Russia of placing satellite vehicles in orbit, and the most recent success of the United States moon rockets. The successful development of an electrical propulsion system will contribute toward satisfying man's curiosity about outer space.

The term thrust generator is purposely used in leading up to the definition and description of an electrical propulsion system. The ion rocket engine and the plasma rocket are two thrust generators which have become familiar to the engineer and the scientist. First, let us define what is meant when these power plants are mentioned.

The concept of the ion rocket engine which will be used here is one of a system which includes three major subsystems—the energy source, the power converter, and the ion thrust chamber. The first two components mentioned are also required for a plasma engine. The thrust chamber of the latter is rather generally referred to as the plasma rocket. In it the gases generated electrically from the propellants are heated to high temperatures, then expanded through a contoured nozzle to produce the thrust in a manner similar to that of the chemical rocket engine.

One concept of an ion rocket engine is summarized in Fig. 1. The thrust chamber, which is the heart of the engine, is delineated by the dashed rectangle. It includes an ion source and an array of electrodes to focus and accelerate them and an electron emitter. Vaporized propellants are fed to the ion source where they are ionized either by contact with heated metals or by being subjected to electron bombardment. The fully ionized propellant is then conducted through the focusing electrodes and the accelerating electrode, which imparts kinetic energy to the ions.

Research discussed herein was performed under sponsorship of the Directorate of Advanced Studies, Air Force Office of Scientific Research, ARDC. Participating engineers and scientists were A. L. Huebner, S. L. Eilenberg, R. H. Gersten, W. A. Moser, and F. M. Ferebee.

Holder of Ph.D. and M.S. degrees in physics from the Massachusetts Institute of Technology, Dr. Robert H. Boden—now Project Engineer, Advance Design Section, on the ion rocket engine research program at Rocketdyne—made the original proposals at Rocketdyne to utilize electronic computing in analysis of complex engineering data from rocket engine tests. He also organized the first numerical analysis groups at the North American Aviation division and directed installation of the system there. Boden's current field of prime interest, the ion engine, is being studied for possible use in unmanned outer space vehicles.

Power to drive the ion thrust chamber is obtained from a high-speed electrical power generator which in turn is driven by a gas turbine. The power for the turbine is derived from a high specific power nuclear reactor through a single-loop system using an alkaline metal as the working fluid.

The ion rocket engine model shown in Fig. 1 is a concept which it is believed will result in an engine of minimum weight and simplicity. It does not require technical or scientific breakthroughs to achieve a flying model. The individual elements of this engine model are discussed in greater detail later.

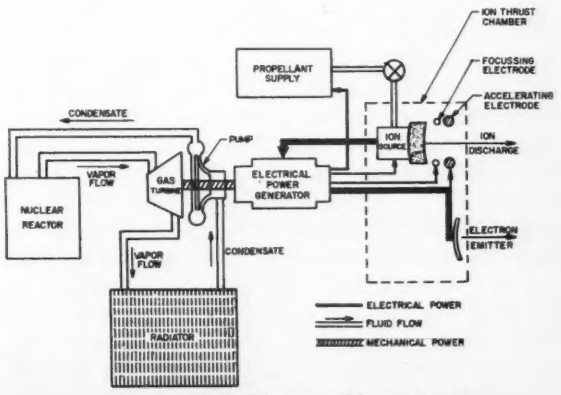


FIG. 1. Typical ion propulsion system.

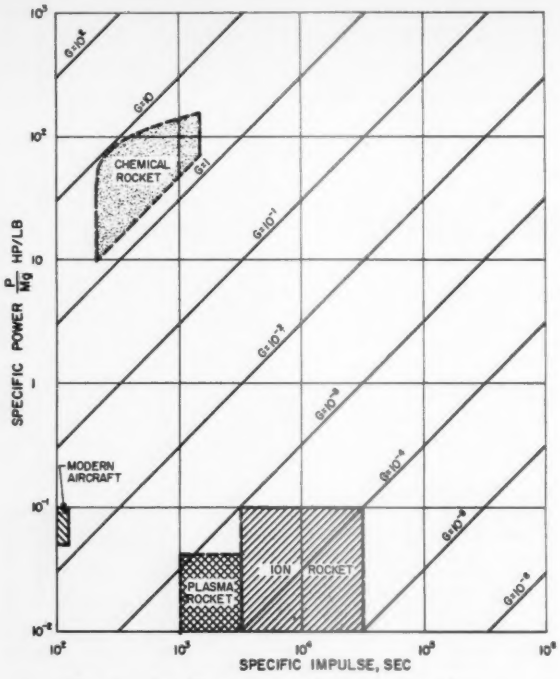


FIG. 2. Specific power requirements of vehicles.

Many other concepts which include heat source other than nuclear, direct power conversion systems, thrust chamber with electromagnetic accelerators in which crossed electromagnetic fields apply the forces to accelerate the ions and electrons, etc., have been conceived and proposed. After evaluation of design and performance problems associated with these concepts, the most favorable system for development within the next few years appears to be the electrostatic engine. Research upon this model is now being conducted at the Rocketdyne division of North American Aviation, Inc., under the sponsorship of the Directorate of Advanced Studies, Air Force Office of Scientific Research, ARDC.

Historical

The concept of the ion rocket engine is not a new one. Herman Oberth devoted a chapter to a solar-powered ion rocket in his classic *Wege Zur Raumschiffahrt* published in 1929. In this document Oberth mentions an earlier investigator, the Russian Ulinski, who proposed the engine about 1923. There are unconfirmed reports that an English researcher suggested an ion rocket engine at an even earlier date. Since then ion propulsion has been examined by L. R. Shepard and A. V. Cleaver of Great Britain, in 1947 and 1948; Prof. L. Spitzer, Jr., of Princeton University in 1951; H. Preston-Thomas of Great Britain in 1952; and D. C. Romick and Dr. Ernst Stuhlinger, now of the Redstone Arsenal here in the United States, in 1954. These studies were largely general in nature, being the work of individuals. They all predicted that ion rocket vehicles are capable of attaining velocities which are higher than those obtainable with chemical rockets having the same payload and gross weight.

In January, 1957, an analytical study of the ion rocket was initiated at Rocketdyne under the sponsorship of the Directorate of Advanced Studies, AFOSR. This was the prelude to an experimental research program which was initiated at Rocketdyne under the same sponsorship early in 1958. It is believed that the first ions produced with the idea of vehicle propulsion in mind were generated at the Research Laboratories of Rocketdyne. These studies are now continuing at an accelerated pace.

General Discussion

The ion rocket engine presents four major problems—the heat source, the power conversion system, the ion thrust chamber, and the propellants. The overall requirements for these components are examined in the following discussion.

When installed in a vehicle for travel in outer space, the engine system is subjected to forces during the boost phase varying from 1.5–2g up to 7–15g at burnout. Once established in a satellite orbit, the vehicle settles down, and only low-acceleration forces need be dealt with. The engine must be structurally sound to withstand boast loads.

The engine may be installed in a final stage of the rocket. Let us assume that it is used for vernier control of the flight path. This presumes that sufficient velocity is imparted to the vehicle to reach its destination. It will be shown later that a thrust-to-weight ratio G of 10^{-4} is a reasonable value to be expected in an ion-powered vehicle. Let us build in a capability of achieving a velocity change Δv of 3,600 ft. per sec. if the terminal velocity of boost is 36,000 ft. per sec. This is a 10 per cent safety factor. The time to achieve this velocity change[1] is obtained from the relation

$$t = (0.0311\ \Delta v)/3{,}600G \text{ hours} \qquad (1)$$

Under the ground rules set up for this control application, the engine must be capable of operating up to 311 hours, nearly 13 days.

If sufficient power is available in the vehicle to step up the thrust-to-weight ratio to 10^{-3}, this time can be reached to 1.3 days.

A mission to the moon or to Mars from a hundred-mile satellite orbit presents quite a different picture. Analyses performed on an automatic digital computer at Rocketdyne of a mission to circumnavigate the moon predict that the engine must operate continuously for about 1,820 hours, nearly 76 days. This time is extended to 323 days, nearly 11 months, to reach Mars.

These assumed missions present a picture of the range of lifetimes over which the ion rocket engine must operate reliably and at full rated power. The minimum times have been frequently achieved by modern aircraft. Very few, if any, high-performance power plants have operated for the periods demanded by the larger space missions.

How much power is required is estimated from

analyses based on Newton's laws of motion. For the purposes of this discussion, it is assumed that all of the ionized particles ejected to develop thrust have the same velocity and mass.

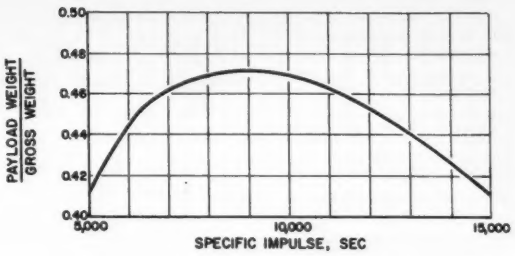
The specific power requirements of the exhaust jet are graphically summarized in Fig. 2. The ordinate is the specific power, horsepower of the jet exhaust per unit vehicle weight. The abscissa is the specific impulse Isp, expressed in seconds. The specific impulse is the length of time in seconds that the engine will operate on a supply of fuel, equal in weight to the thrust. The variation of the specific power with the specific impulse is shown for several values of the thrust-to-weight ratio G of the vehicle in which the power plant is installed.

The operating regime shown for the modern aircraft is computed for full power rating of propeller-driven vehicles at the lower limit of specific impulse and covers the jet-engined aircraft—such as the Boeing 707, Douglas DC-8, and North American Aviation T-39—at the upper limit. The regime shown for chemical rockets covers existing solid- and liquid-fueled vehicles up to estimated performance values of future designs.

The operating range shown for the plasma rocket is based upon tentative estimates. At this time it is difficult to predict the overlap in performance of the plasma-powered vehicle on the ion-powered craft. The solar-powered rocket does not appear in this figure because the specific power of this vehicle is nearly two magnitudes less than that of ion or plasma vehicles of the same gross weight. It is noted here that the chemical rocket potentially is capable of filling the gap between the gas-turbine-powered aircraft and the plasma or ion rocket simply by applying a smaller rocket engine in a larger vehicle. Theoretically, the ion rocket can operate to much higher values of specific impulse than those shown. Since the specific power of the jet probably cannot exceed 0.05–0.10 hp. per lb., the thrust-to-weight ratios of the higher specific impulse vehicles become very small. This results in much longer times for accomplishing the same mission, and decreased payload.

The results of an analysis to determine the best specific impulse for a given mission in which a velocity change Δv of 96,000 ft. per sec. (Mars mission) is required are summarized in Fig. 3. The ratio of the payload weight to the gross weight of the vehicle is shown as a function of the specific impulse of the rocket engine. In the specific impulse range between 8,000 and 9,500 sec. the change in the payload weight is negligible. This variation of payload is characteristic of such performance curves and indicates that substantial freedom exists in the selection of engine operating conditions. In comparison, preliminary estimates for a mission to the moon are that the specific impulse is in the neighborhood of 5,500 ft. per sec. The velocity change for this mission is from 23,000–25,000 ft. per sec.

The data of Fig. 3 are based upon an assumed efficiency of conversion of electrical power to exhaust jet power of 60 per cent. If this efficiency is 100 per cent,



VELOCITY CHANGE, ΔV = 96,000 FT/SEC
SPECIFIC POWER, = 0.10 KW/LB
ELECTRICAL EFFICIENCY = 0.60
THRUST-TO-WEIGHT RATIO = 0.75×10^{-4}

FIG. 3. Variation of payload with specific impulse.

the payload to gross weight ratio increases to 0.68 at a specific impulse of 11,400 sec.

This brief discussion indicates a number of factors of importance in the design and application of an ion rocket engine. First, the power plant must be rugged, reliable, and lightweight and must produce high power. Since current estimates of the minimum accelerating potential drop is within the range from 10,000–12,000 volts,[1] a relatively high ion weight per unit electron charge is desirable for missions to the moon and near planets in order to obtain a specific impulse lying within the range for maximum payload. Current estimates of the specific power capabilities of typical vehicles indicate that the thrust-to-weight ratio of an ion rocket is approximately 10^{-4}. This in turn results in long travel times for most missions. An ion thrust chamber with the maximum electrical efficiency is desirable to achieve the highest payload.

Power Sources

Heat power for the ion rocket engine may be derived from several sources and later converted into electrical power.

A thermal or intermediate nuclear reactor now appears to be the most promising energy source for applications to an ion rocket engine. Radioactive nuclear cells are too heavy and too short-lived for use in electrical propulsion systems. For nuclear reactors with high thermal fluxes, operating at high temperatures, liquid metals have special interest as coolants. They have excellent thermal properties, high thermal conductivity, low vapor pressure, relatively high specific heats, and volumetric heat capacities. The liquid metals are stable at high temperatures and in intense radiation fields. Nuclear characteristics of many are favorable for use in the reactor. The main disadvantages lie in the difficulty in handling and in the corrosive problems of some materials at high temperatures. For these and a variety of other detailed reasons, liquid-metal-cooled nuclear reactors are being given attention in the ion propulsion research program.

The low weight requirements of the nuclear reactor for the ion rocket engine application appears possible from consideration of core sizes, specific power (power per unit weight of fissionable material in the reactor),

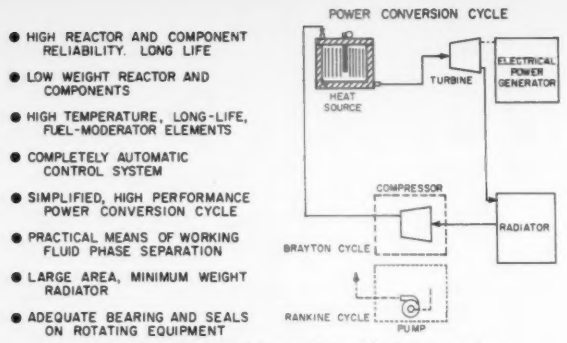

POWER CONVERSION CYCLE
● HIGH REACTOR AND COMPONENT RELIABILITY, LONG LIFE
● LOW WEIGHT REACTOR AND COMPONENTS
● HIGH TEMPERATURE, LONG-LIFE, FUEL-MODERATOR ELEMENTS
● COMPLETELY AUTOMATIC CONTROL SYSTEM
● SIMPLIFIED, HIGH PERFORMANCE POWER CONVERSION CYCLE
● PRACTICAL MEANS OF WORKING FLUID PHASE SEPARATION
● LARGE AREA, MINIMUM WEIGHT RADIATOR
● ADEQUATE BEARING AND SEALS ON ROTATING EQUIPMENT
HEAT SOURCE
TURBINE
ELECTRICAL POWER GENERATOR
COMPRESSOR
RADIATOR
BRAYTON CYCLE
RANKINE CYCLE
PUMP

FIG. 4. Principal problems of electrical power plant.

and structural details of reactors for which information has been released. The active core of the Materials Test Reactor is contained within a 30-in. cube and is capable of developing 30,000 kw. thermal power. The active core of the water boiler research developed by Atomics International Division of North American Aviation is a sphere 12.5 in. in diameter. Cores of fast reactors are quoted to have core sizes ranging from 6 in. by 6 in. cubes to the size of footballs, depending upon the power output. Such cores, adapted for use with the liquid metals for heat transfer and incorporating light metal reflectors and shielding, are estimated to be of such a weight that an overall vehicle specific power (power in the jet per unit of vehicle weight) of 0.05–0.10 can be achieved. This results in a vehicle thrust-to-weight ratio in the neighborhood of 10^{-4}.

Solar energy has been suggested frequently for use in satellite and space vehicles. An inherent difficulty for propulsion is the low level of the energy incident on a collector. The collector size becomes large, and the estimated thrust-to-weight ratio of the solar rocket is less than 10^{-6}. This implies that completion of a mission with a solar rocket requires 100 times as much time as that required with an ion rocket vehicle powered with a nuclear reactor. For other than specialized applications, the solar rocket does not appear to have immediate promise.

Power Conversion Systems

Power conversion systems for an ion rocket engine have been narrowed down to closed-cycle gas-turbine systems. Summarizing current surveys briefly, photovoltaic cells weigh approximately 200 lb./kw. The specific weight of thermoelectric generators is an order of magnitude greater than for photovoltaic cells. In addition, thermoelectric devices operate on a modified Carnot cycle which requires radiation of rejected heat. Because of these factors, the power section of early ion rocket designs will not include these unconventional systems. Current predictions are that a nuclear reactor and advanced mechanical power conversion system will be adopted.

Mechanical systems for converting heat to mechanical energy include gas cycles (the Brayton cycle), and condensing cycles (the Rankine cycle), both single-loop and binary. Fig. 4 summarizes the major elements and significant technical problems of typical mechanical systems. A single-loop system is shown.

Helium is an excellent working fluid for an all-gas system. A Brayton-cycle working fluid that directly transfers heat from the nuclear reactor requires the following characteristics: (1) stability under nuclear radiation, (2) a low neutron absorption cross section, (3) low chemical activity, (4) compatibility with structural materials, (5) good heat-transfer properties, and (6) low density. Hydrogen, helium, carbon dioxide, nitrogen, and air satisfy these criteria. Helium is superior.

Rankine-cycle working fluids must have the characteristics of the gaseous working fluids and, in addition, the characteristics of (7) high latent heat of vaporization, (8) a vapor pressure sufficiently low at reactor temperatures to avoid heavy pressure shells, and (10) a vapor pressure sufficiently high at radiating temperatures to avoid cavitation and other pumping problems. Water, the alkali metals, and their alloys—sulphur and phosphorous—are materials which satisfy these requirements to some degree.

Typical power-plant performances are summarized in Fig. 5. These were obtained using standard engineering methods of analysis and assuming a specific set of operating parameters. Condensing systems using the Rankine cycle are superior because of less heat demand. They are far superior to gas cycles because of lower radiator requirements and potentially lower operating pressures.

Electrical Power Generators

Conversion of the mechanical power from closed-cycle gas-turbine systems presents an optimistic picture for the ion rocket engine. Applying existing design techniques for rotating electrical machinery, three alternatives appear satisfactory—the permanent magnet generator, an a.c. induction generator, and the electrostatic generator. These three generators are all estimated to develop at least 1 kw. per lb. of weight with an efficiency exceeding 90 per cent when operated at high speed. Cooling and radiation damage may be serious problems for the electromagnetic types. These factors are not expected to affect the vacuum electrostatic generator seriously. It is estimated to be the most satisfactory for application to the ion rocket engine system.

WORKING FLUID	CYCLE	TURBINE INLET PRESS PSIA	REACTOR OUTLET TEMP (°F)	RADIATOR* AREA SQ FT	REACTOR* POWER MW
HELIUM (WORKING FLUID & COOLANT)	BRAYTON	1500 1500	1900 1500	8800 12300	4.00 5.26
HELIUM (SODIUM COOLANT)	BRAYTON	1500	1460	21400	6.25
MERCURY (SODIUM COOLANT)	RANKINE	5000 2500 1200 500	2000 1800 1600 1400	1100 1700 2000 3200	4.00 4.16 5.26 5.26
ALKALI METAL (WORKING FLUID & COOLANT)	RANKINE	460 217 89 31	2000 1800 1600 1400	1000 1300 1500 3400	3.57 3.57 4.16 7.14

* FOR ONE MW MECHANICAL POWER OUTPUT

FIG. 5. Operating requirements for mechanical power conversion systems ion rocket engine.

Thrust Chamber

The ion thrust chamber includes three basic components—an ion source, an accelerating electrode array for the ions, and an electron emitter. Two types of ion sources are applicable to the ion rocket engine—the arc type and the surface contact type.

The so-called arc source is not like the conventional arc struck from two electrodes as in the carbon arc so often used for concentrated light sources. As defined here, the arc is the phenomenon taking place within a gas which is subjected to electron bombardment under the influence of accelerating electrostatic fields and collimating magnetic fields. Collisions between electrons and gas atoms, or molecules, produce ions and additional electrons. The latter, because of secondary collisions, multiply the ion yield. The arc source has disadvantages in comparison with surface contact sources. These include increased complexity, a tendency toward unstable operation, the production of mixed species which lower the effective ion weight, and a lesser efficiency. A distinct advantage exists for the arc source in that it is capable of ionizing a much wider variety of propellants.

The surface contact source depends upon the controlled evaporation of propellants from a heated plate. To obtain positive ions from the heated plate, the thermionic work function of the plate must be larger than the ionization potential of the propellant atom. Proper selection of the propellant and the materials of the plate results in a ratio of ions produced to propellant atoms evaporated which approaches unity. Application of this technique results in highly efficient sources. Some decrease in overall efficiency may be expected from radiation losses of the heated plate. Current estimates predict that the surface contact source will be lightweight, relatively simple to control, and long-lived. The propellants which can be ionized in this source are limited in number.

Ions produced by the source are extracted and accelerated by an array of accelerating electrodes. An additional function of these electrodes is to direct the ion jet into a well-collimated beam so that the momentum imparted to the ions is not dissipated in useless side thrust. This function is similar to that of the nozzle of the chemical rocket. Another purpose of the electrode array is to prevent the ions from striking any part of the engine structure. Since they are of high energy, each collision results in sputtering off several atoms of the structural material and can result in damage or destruction of the structure if not controlled.

Electrons, released and collected at the ion source, are pumped off as electric current through the electrical power generator to the skin of the vehicle parallel and equal to that of the ion current. If the ion and electron currents are unequal, space charge effects stop the ion flow in a small fraction of a second.

Two methods of electron generation appear readily adaptable to the ion rocket engine. One is field emission from properly positioned metallic probes in the neighborhood of the ion jet. The other is by thermionic emission from a heated plate of tungsten, tantalum, or other suitable material. Electron emission in this application is believed to be a self-controlled phenomenon and presents little difficulty of accomplishment.

Propellants

Propellants pose several problems, many of which are similar to those of the chemical rocket engine. Corrosiveness, materials compatibility, toxicity, handling techniques, and availability are a few of this type. Ionization must be possible, complete, and efficient. In order to minimize the specific power demands from the vehicle, it is desirable to select propellants which will produce relatively heavy ions. This selection is conditioned by the mission and the operating voltages of the rocket engine. The reasons for this are that the specific power of the vehicle increases rapidly with the ratio of operating voltage to the ion weight, and there is a preferred specific impulse for each mission.

The high atomic weight alkali metals are popular because of their low boiling point, ease of ionization in any type of source, and high efficiency of ionization—particularly in surface contact sources. Cesium (atomic weight 132.9) undergoes 100 per cent ionization on tungsten metal over the temperature range from 1,700° to 3,200°F. Rubidium (atomic weight 85.5) exhibits the same high ionization over a narrower temperature range, 1,700° to 2,100°F. Lower atomic weight alkali metals do not approach this efficiency of ionization.[2]

Chemical compounds such as uranium tetrachloride can be ionized in arc sources but at lower efficiency than the alkali metals. The compounds break down into a variety of ionic species. Uranium tetrachloride produces ions with a range of weights from 380 (UCl_4^+) to 17.8 (Cl^{++}). The species and concentration depend upon the operating conditions of the source. The effective ion weight in the jet varies from less than 100 to above 200.

At this time cesium and rubidium are good choices for experimental ion rocket propellants.

Conclusion

This paper has demonstrated the problem areas of the ion rocket engine, the heat source, the power converter, the thrust chamber, and the propellants. No attempt has been made to decide the controversial issue of which is the most important. All must be solved concurrently before a successful flight prototype is developed. When solutions are accomplished, it is believed that an engine system will be available which, while it cannot be of use without the chemical rocket, will supplement the chemical rocket for space flight. Applications are believed to exist for missions requiring high payloads, missions to distant planets, and positional control of satellite vehicles.[3] Many of these

(*Continued on page 75*)

". . . The challenge to produce ceramic materials of greater strength and reliability so that aeronautical designers may exploit their well-known abilities to withstand extremes of temperature and abrasion has accelerated the use of newly acquired scientific skill and new materials."

Aeronautical and Space Applications for Ceramics

James D. Welterlen
Gladding, McBean & Co.

THE CERAMIC INDUSTRY, which is characterized by a myriad of commercial products which have been changed little in decades or centuries, is finding the tools to satisfy the startling demands of the fast moving aviation and missile industries. The challenge to produce ceramic materials of greater strength and reliability so that aeronautical designers may exploit their well-known abilities to withstand extremes of temperature and abrasion has accelerated the use of newly acquired scientific skill and new materials. The result of this effort has been a new order of ceramics which bear little resemblance to their clay counterparts. These new materials are characterized by purities above 90 per cent, near theoretical densities, and have created new processing techniques which no longer rely on the natural plasticity of clay materials but on additions of organics. Recent advances have come at a rate found in the aviation and electronic fields themselves. The problem of reviewing the highlights of these advances is attempted here, with reference for further study by the reader.

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Properties of the New Ceramics

The primary interest for ceramics in aeronautics has been prompted by the desire for high temperature and oxidation resistance. Table 1 lists some of the more frequently used ceramic materials and their melting points which range from 1900°C. to 2700°C. Of further importance is the excellent resistance to rain erosion which some of these materials exhibit. Exposure of aluminum oxide to a Mach 2 rain field has only cleaned the surface of the ceramic but virtually destroyed the supporting metal fixtures. The high modulus of elasticity of these materials may be put to good use in structural components reducing flutter. In the electronic field, ceramic materials of the titanate group are utilized to produce a wide range of dielectric constants and temperature coefficients in components. Magnetic ferrites serve in memory devices and cores at elevated temperatures. Ceramic vacuum tubes capable of operating in high ambient temperatures and under severe vibration and shock conditions have been introduced. It has been found that these ceramics possess excellent resistance to nuclear radiation and are proposed for electronic, structural, and functional components in aircraft propulsion systems.

TABLE 1

	Melting Points, °C.	Limitations
Carbon	3700°	Oxidizes
Tungsten	3410°	
Thorium Oxide	2700°	Expensive
Zirconium Oxide	2500°	Expensive
Beryllium Oxide	2400°	Expensive, toxic
Magnesium Oxide	2400°	Hydrates
Calcium Oxide	2400°	Hydrates
Aluminum Oxide	1950°	

The outstanding characteristics of some of these new ceramics are reviewed here individually.

Aluminum Oxide

More commonly referred to as alumina ceramic, this material is one of the most frequently used of the new ceramic materials. It is characterized by a superior strength, excellent impact resistance, hardness, and outstanding electrical insulating properties. It is also stable in a wide variety of atmospheres and in contact with most chemicals. The full tensile strength of this material is maintained above 2000°F. and it may be used structurally as high as 3000°F. under some conditions. In Table 2, alumina is compared in hardness with diamond and other abrasive materials.

Beryllium Oxide

Although toxic, this material has received considerable attention due to its extremely high thermal conductivity; values forty to fifty times that of ceramic porcelain and approaching metallic aluminum are reported. Beryllia further exhibits high "hot" strength, and, as such, is a prime candidate for applications where extremely high temperatures and thermal shock are encountered. It is useful in nuclear devices as a moderator for "fast" neutrons, reducing them to "thermal" neutrons.

Magnesium Oxide

One of the most abundant refractory oxides, this material exhibits a high melting point and is comparatively easy to fabricate. It possesses the disadvantages of high thermal expansion, a tendency to hydrate, and volatilizes above 2300°C. It is further limited to a temperature of 1700°C. in reducing atmospheres.

Thorium Oxide

This is the highest melting ceramic oxide. It has a low vapor pressure at temperature, but it exhibits relatively poor thermal shock resistance, and is radioactive.

Zirconium Oxide

Zirconia is of interest for its very low thermal conductivity which has proved valuable in insulating heat sources or conductors from attached assemblies. It is very stable, has a high melting point and a moderate thermal expansion. It is normally stabilized with small additions of calcium oxide, yttrium oxide, or magnesium oxide to obtain greater thermal shock resistance.

Carbides

Familiar materials in this group are silicon carbide, titanium carbide, and boron carbide. These are an extremely hard class of materials, but exhibit limited stability in air or oxidizing atmospheres at high temperatures. *Borides*, a similar class, are slightly more stable than the carbides. *Nitrides* are of limited interest due to brittleness and poor oxidation resistance. *Silicides*, as a group, are lower melting materials; however, they possess excellent oxidation resistance and thermal shock properties. Molybdenum disilicide is the only commercially produced silicide at present. An excellent reference on these materials is contained in *High-Temperature Technology*[1] and is recommended for detailed physical, electrical, and chemical data.

TABLE 2

Material (Bureau of Standards)	Hardness Knoop
Diamond	6000–6500
Silicon Carbide	2000–2500
Alumina Ceramic	1450–1750
H S Steel	650–900

Processing

In addition to conventional ceramic fabrication techniques as casting, powder pressing, and extrusion, a number of new techniques are being utilized to achieve greater density, strength, and uniformity in the new ceramic materials. Hydrostatic pressing of powders at pressures as high as 100,000 psi has been used to improve density and, in particular, to reduce sintering shrinkage enabling larger precision shapes to be formed without the expensive diamond grinding necessary to shape fired ware. Fabrication of radomes and tubular shapes has been particularly successful using this process.

Aluminum oxide films of one-millionth inch thickness (or 25 to 50 molecules) which are self-supporting have been produced by simple laboratory techniques. The film exhibits properties of a two-dimensional solid and is transparent.[2] Thin films of titanate have been produced for capacitor and piezo-electric uses utilizing a continuous casting technique. Another proprietary method for producing thin ceramic sheet continuously has been introduced for the production of ceramic printed circuit boards of alumina and steatite. Hot pressing techniques have yielded ceramic shapes with improved structural properties. In this method, pressure and high temperature are applied to the ceramic powder concurrently. At the present time, the size and complexity of shapes which may be produced by this method are limited and the electric power required for large shapes is generally a problem. Recent studies of single crystals have been of considerable interest.

FIG. 1. Ceramic radomes are fabricated by hydrostatic pressing of a solution containing as high as 99 per cent alumina which has been sprayed on a special steel mandrel.

Magnesia crystals have exhibited ductility under certain conditions with compression of 10 per cent, extension of 1 per cent and bends up to 50 per cent. These studies have led to the prediction that ductile polycrystalline ceramics will emerge in a few years.[3]

Applications

Radomes—Nose Cones

Considerable effort has been made to produce ceramic radomes both of thin wall, dense structure using alumina, and a sandwich construction utilizing various porous ceramic materials (Fig. 1). Exhibiting excellent dielectric properties and dimensional stability, these materials are proposed for the high-performance interceptor missiles.[4] Ceramics may also play a part in re-entry bodies where porous ceramic structures are impregnated with ablating substances forming a structure capable of withstanding extreme surface temperatures.

Airframes

Dense ceramics, notably alumina, have been proposed for the airframe structure itself and structural evaluations have been reported.[5] Sandwich or honeycomb structures have also been fabricated. Fig. 2 compares some of the high temperature alloys to ceramics, and we note that at temperatures above 1800°F. the ceramic comes into its own. On a strength to weight ratio basis, alumina surpasses Inconel X at temperatures above 1400°F.[6]

Rocket Nozzles

A number of approaches to the problem of lining rocket thrust chambers have been made, including ceramic coatings on metal and monolithic ceramic structures. Silicon carbide bonded with silicon nitride has been used with some success.[7] Zirconium oxide bears further investigation. Various combinations of ceramics and ablating materials are being investigated. The hydro-pressing techniques described provide a solution to the complex fabrication problems involved. The resistance of ceramic materials to abrasion, oxidation and high temperature are of considerable value in this area. Some of the experimental designs for ionic propulsion devices also utilize ceramic materials acting as insulators for high voltages and containers for cesium flow.

Airfoil Surfaces

The use of ceramics for leading edge structures is extremely promising, particularly due to their resistance to rain erosion previously mentioned. In addition, radar windows of varying sizes and electrical insulators exposed to high-surface temperature are in use on high-performance aircraft and missiles.

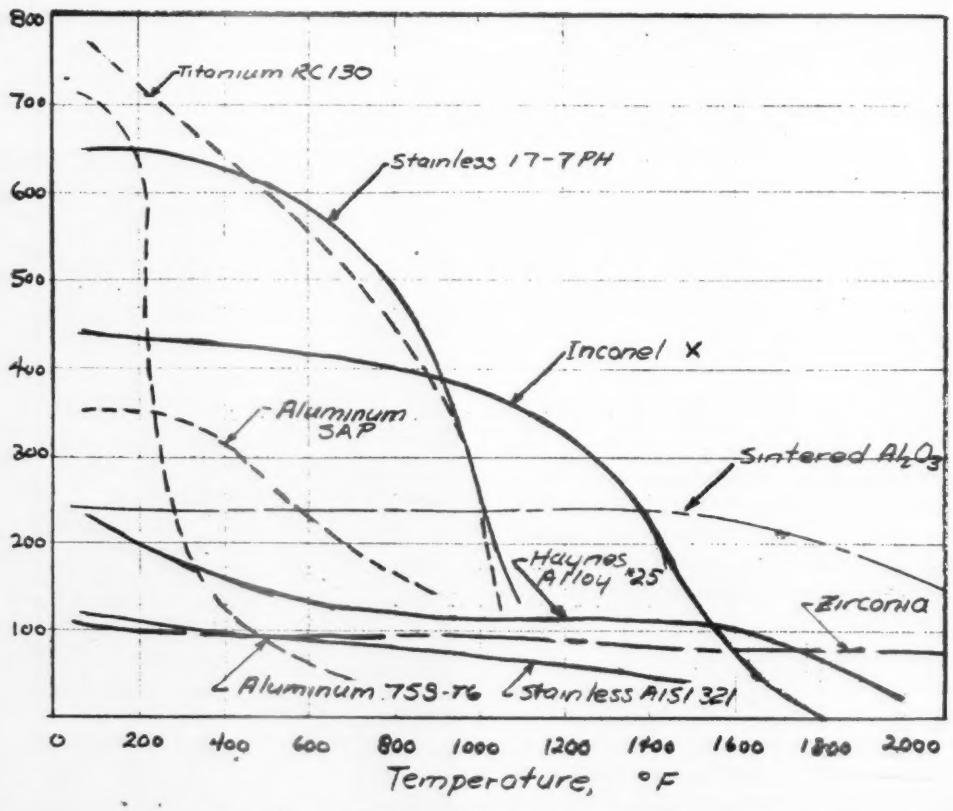

FIG. 2. Strength-weight ratio vs. temperature.
Strength-weight ratio (ordinate) = tensile yield strength (ksi)/density (lb./in.^{3}).

Electronic Equipment

The ability of ceramic electronic components to withstand nuclear radiation and high ambient temperature suggests their use in space vehicles where radiation-tolerant rather than radiation-protected devices will serve to advantage. Techniques for assembling ceramics and metals in vacuum tight assemblies are well advanced, and miniaturized sealed devices are proposed. A number of electronic circuits utilizing ceramic tubes, ceramic film resistors, ceramic mounts, and ceramic coated wire have been operated successfully under intense nuclear radiation at temperatures to 1500°F.[8] (Fig. 3).

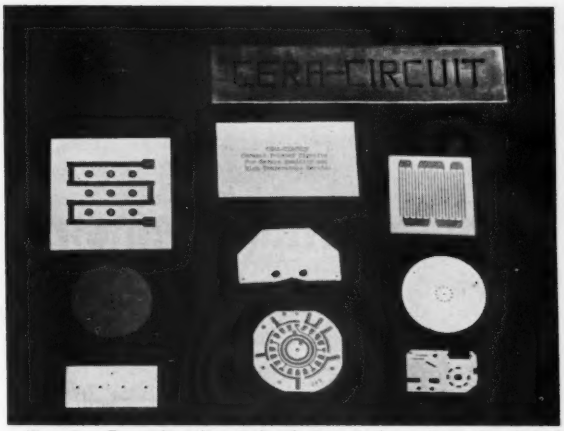

FIG. 3. Ceramic printed circuit boards have been developed which will withstand temperatures up to 2000°F. and all extremes of humidity.

Tooling

Hot forming techniques required for many of the special metal alloys require the application of ceramic in forming fixtures and related equipment. Ceramic brazing jigs have been fabricated for large brazed assemblies as rocket thrust tubes. These jigs aid materially in the even application of heat to the brazed areas eliminating chilling and braze embrittlement. Refractory castables have been successfully used in fabricating brazing fixtures for honeycomb brazing and in similar processes where extremely large jigs of close dimensional tolerances are required. The castables may be poured or rammed directly on a model surface at the factory site. These ceramic materials are selected for extreme resistance to thermal shock, and will withstand the rigors of torch brazing and direct flame impingement without failure. Closely related to these developments is the use of precision ceramic molds for powder metal sintering, replacing sand core and carbon mold assemblies.

Conclusion

The complexity of requirements for ceramic materials in the frontiers of aeronautic development have induced a number of ceramic firms to attempt to contribute to the solution of the problems presented. They, in turn, have benefited from the thinking of chemists, physicists, and metallurgists, and have found new scientific approaches to many of their own problems. The willingness of ceramists and the ability of ceramics to contribute to the space age is limited only by the number of perplexing demands which are placed upon them.

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Ion Rocket Engine Systems *(Continued from page 71)*

missions are beyond the capability of conventional chemical rockets. However, these mission capabilities are sufficient for a separate, and extended, dissertation.

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"Committees do not solve problems; they are a crutch or an aspirin.
The poorer the management, the more committees you will find.
Free your design people from committees by managing better."

Edgar Schmued, an engineering and management consultant, resigned in 1957 as Vice-President—Technical of Northrop Aircraft, Inc., 5 years after joining the West Coast airframe manufacturing firm as Vice-President in charge of Engineering. Much of his early career was devoted exclusively to design and management, a field in which his interest is extensive. He was elected an IAS Fellow in 1955 and is a member of *Aero/Space Engineering*'s Editorial Advisory Committee, serving on the Design, Structures, and Materials Panel.

Technical Management

From Airplanes to Space Vehicles

Edgar Schmued, FIAS
Consultant

It is the purpose of this paper to touch quickly on the past, discuss briefly how well its experiences have been applied, and try to determine how best we might achieve greater successes by using less precious time and hard-to-get money in the future.

Just what is it that causes the materialization of great technical advances? The writer holds that it is superior understanding of technical facts, the willingness to risk setbacks, the desire to analyze failures for the better understanding of underlying factors, and, possibly, the glorious pride of achievement. Let us see if this is so.

Serious thinking in the realm of flight by man was done by da Vinci, of course, long before the reality of aviation at the turn of our century. Progress made by the Wright brothers is well known—in their work may be seen some of the finest examples of good detail design. After their early successes, the French scientist, Eiffel, who did many free-fall flight researches and wind-tunnel experiments, extended knowledge in the art appreciably. In 1908, Eiffel published his classical *Le Resistance de l'Air*, which is recommended to any student of aerodynamics as a primer. Work in theoretical aerodynamics also was being carried on in Russia, outstandingly represented by Youkowsky.

Suddenly, we had World War I and with it the question, "How are we going to use airplanes militarily?" The pressure of war brought many refinements, yet really no startling developments—with the possible exception of all-metal design. But it served to intensify the search for fundamental knowledge and establish more firmly the various scientific disciplines serving aviation. Universities taught aerodynamics, structures, and other subjects as related to aviation. The military services had well-established (though lean) plans for aviation. The NACA came to life, and, as the saying goes, we were in business. We didn't make any money, progress wasn't too startling, but even so, we reached the age of the all-metal stressed skin airplane and the 400–500 hp. engine.

In the pre-World War II period, the NACA, universities, and private firms with small wind tunnels slowly accumulated a substantial amount of sound knowledge, and at the beginning of the second "Great War" the large steps of progress from the 1917–1918 period became apparent. We were technically and scientifically ready to face the challenge of a well-prepared enemy.

Industry, as well as the Air Force, was now faced with a new problem which in the past was of relatively little significance. The management of enterprises which mushroomed in size more than twentyfold became a real challenge which even today is not completely solved and, with the entry into the missile field and space technology, demands greater efforts and better methods if we are to be successful as a nation.

I believe it was fortunate that the war did not end a few years later. It would undoubtedly have had an adverse effect because we would have had to enter the jet and missile age unprepared. Just how serious this might have been becomes apparent if we look at the time scale of our operational jet planes and missiles. It took almost 5 years after World War II before we had an operational jet capability, and more than 10 years to have missile capabilities. Again, this may prove that sound scientific knowledge, engineering experience, and manufacturing and operational know-how are required before success is to be achieved.

While World War I served primarily to separate scientific fact from fiction, World War II found us scientifically much better equipped and subsequently enabled us to gain technical breakthroughs, particularly toward the end of the war, as—for instance—jet engines, radar, new and vastly more powerful weapons, and a great number of technical refinements in aerodynamics, structures, equipment, materials, and methods.

We also learned to manage large plants, a great number of employees, enormous budgets, and production quantities.

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A major change in this general pattern of experience came immediately after the war. With the entry of our industry into the missile field, the super- and possibly hypersonic manned vehicle, and the coming exploration of space, a new pattern of science, engineering, operation, manufacturing, and management emerged. What kind of pattern is this? Is it firm or in a state of flux? Can we learn from our past mistakes and apply this experience to the future?

Again, World War I served to establish and confirm knowledge. No startling developments resulted which could not be fairly well predicted.

World War II brought new knowledge, a number of breakthroughs, a good balance between engineering and manufacturing, the emergence of the electronics industry, the weapon system concept, bold weapons, and bolder thinking.

At the beginning of World War II, engineering staffs were small, well seasoned, and trained for attention to detail. Science played an advisory role.

During the course of World War II, the influx of new manpower into our engineering departments degraded the attention to detail because the more experienced supervision was spread far too thin and eventually became overburdened with paper work. Some of the beginners had more up-to-date schooling which to some degree made up for lack of experience. In some cases they were so ignorant of the technical facts of life that they did not realize that certain things could not be done—and so they did them.

During the war a substantial effort was made by Dr. von Kármán to enlist the scientific community of this country into the war effort. Instead of being consultants, scientists became involved in research and development problems which led to great advances and breakthroughs and left their imprint on many technical developments. This was an important departure from the past and had a decisive effect on the postwar pattern of our industry.

This event also created new problems for management and the interaction of science and industry which are far from being solved.

The transition from aircraft to missiles in the industry was a step from enlightenment to dark ignorance. The managements of those companies faced unknown problems and tried to solve them in a peculiar fashion by setting up missile divisions that were manned by technically competent but managerially inexperienced people.

The large area of unknowns, coupled with lack of experience, magnified technical problems to such an extent that a great amount of time was lost and great sums of money wasted. The areas which were particularly sensitive were:

(a) The conceptual approach.
(b) State of the art.
(c) Attention to the quality of details.
(d) The haziness of the boundaries of breadboard, experimental, and production stages.
(e) Environmental data.
(f) Reliability and qualification procedures.
(g) General design experience.
(h) Test facilities, procedures, and instrumentation.

(a) The conceptual approach in the missile field was hazy, uncertain, and groping, in contrast to the aircraft field which was direct, sure, and clear.

The reason for this difference was primarily the difference in experience, design data, and judgment. Because proper allowances were not made for this difference, a number of projects were started and often bogged down, were cancelled, or were completed too late to be useful.

The fateful lack of R&D funds has greatly contributed to unwieldiness of these contracts and curtailment of R&D efforts before production was contemplated. Too much breadboarding was carried into the R&D phase and even into the production stage with the inherent tendency to produce failures that could well have been predicted or avoided if better management, experience, less pressure, and more attention to details had prevailed.

Airplanes, missiles, and space vehicles have many things in common as to basic structure, power plant, communication, control and guidance, ground-support equipment, etc. What makes these three so different is the great variation in the degree of the same state of the art which may differ in several orders of magnitude from one to the other.

The most careful analysis of the problems involved is required, with the greatest attention to details; only a thorough knowledge of the environmental condition can minimize the overall problem to such a degree that it becomes manageable.

There is absolutely no room for expedient sloppiness, short cuts—involving risk in quality—or any second-rate effort.

Better conceptual thinking will come with more experience, better state of the art, and better knowledge of the environmental problems.

(b) The development of state of the art can be brought about only by separating this phase from the system concept and by adequate funding, which is usually hard to get unless it is tied to a weapons system. In all cases this stage of development should be done by firms that have a solid background of accomplishment. The reorientation of the Defense budget as far as R&D work is concerned may possibly solve the funding problem.

State of the art developments that are tied to weapons systems suffer from lack of consistency and are often subject to excessive pressure. Also, because of the fact that a weapons system contract allows only a certain portion for the development of components, a one-way approach is often mandatory although detrimental.

(c) Attention to the quality of details is largely a matter of design, experience, and management. With proper emphasis from the Engineering top management, more attention to detail can be fostered and obtained. A better knowledge of the capability of the

available manpower will give supervision a substantial leverage in producing better details. Knowledge is of little use here if it is not accompanied by a great deal of experience.

(d) As previously pointed out, breadboarding should be confined to the early stage of verifying arrangements, and discarded conceptually as soon as proved. To avoid a carry-over of breadboard philosophy, it should be carried out by people not concerned with R&D and production concepts. At the end of the breadboarding phase, the physicist should stop and leave the actual design to the engineer. This rule is frequently violated and may result in serious deficiencies.

(e) Environmental data must be gathered without guesswork. Every dollar spent in determining the environmental condition under which components will have to function saves ten dollars or more later on, not to mention the fact that careless assessment of the environment has resulted in the loss of million-dollar hardware due to the failure of a ten-dollar item.

Here again, the lack of adequate R&D funding and excessive optimism of what can be done by assuming conditions that should have been experimentally established are to a large degree to blame for great losses in time, money, and progress.

The realization of these facts has only lately gained enough recognition to influence materially some of the later projects for the better, but much more must be done before we really get to the core of the environmental problem.

Many more *simultaneous* environmental tests must be made, instead of testing for individual conditions.

When this phase has had a thorough evaluation, let us consider the following:

(f) Reliability and qualification procedures which must be established and which have the same meaning to everyone concerned. The worst confusion exists at this time when the term "reliability" is used.

There is far too much reliance on statistical evaluation without defining and determining the meaning of the statistics. The term "mean time to failure" is almost meaningless unless the frequency of the failure, the degree of failure, and the reason for failure are known. Under certain circumstances, the number of samples is too small and the cause of failure too difficult to define to have any statistical value.

The frequency of stop and go and the operational requirements of possibly a low-level activity for quick warmup or a high-level continuous function, or operation, will require a substantial amount of work before they may become part of a statistical exercise. Entirely too much credence is placed on such data without looking at the hardware at the same time. Closely linked to the foregoing are qualification tests. A thorough understanding of the environment is necessary before any qualification testing can be conducted. Unless a large number of samples are to be tested, it is necessary to test for more severe conditions to establish the margin of quality. Many devices today—although passing qualification tests—are marginal, and the worst of it is that the margin of quality is unknown. Again, I must point out that quality is a design problem first and last. Inspection measures only interpretation of a design drawing by the shop. The quality of the design is determined in Engineering, which brings us to the influence of general design experience in the life of a product.

(g) Because of the great demand for technical graduates, the experience level has come down. This puts a particular burden on supervision. Unfortunately, some of the most experienced design people are now engaged in extensive paper work, administrative problems, company meetings, and traveling. The demand of the customer to send only technically competent people to meetings, briefings, and discussions has further aggravated the supervisory problem and greatly reduced the time which a supervisor may spend with his designers. To raise the quality of design details, something must be done to keep the most experienced design engineers in closer contact with technical problems. Many committees could be abolished by placing an individual in charge of a function and holding him responsible.

Committees do not solve problems; they are a crutch or an aspirin. The poorer the management, the more committees you will find. Free your design people from committees by managing better. Similarly, it is a management responsibility to regulate traveling so that for any little brush fire the most valuable people are not used as a bucket brigade.

It is high time that our industry begin to understand that the only thing which brings contracts is technical competence, and such competence can be created only at the designer's board and nowhere else. Increase supervision if all else fails—it is the cheapest way to better details.

(h) Much can be said about test facilities, procedures, and instrumentation. They are the most essential tools in determining the environmental conditions, and, without knowing those, it is impossible even to plan a qualification test facility. In many cases, the test facilities required to test for proper environment were commercially unavailable and had to be built to specification at great cost (mostly not anticipated nor contractually covered), loss of time, and schedule slippage. In other cases, completely new methods of instrumentation had to be developed. Lack of foresight to tackle these problems—early in the game—led to costly failures, cancellation of contracts, and loss of good will. Many new testing procedures must be developed without which the best testing equipment and instrumentation is useless.

Despite waste, lack of understanding, lack of funds, poor management, and unjustified optimism, many substantial achievements have been made. The saner part of our scientific and engineering population should take credit for that. More than ever before, we must keep our feet on the ground and our heads out of the

(*Continued on page 82*)

"A manned earth satellite having a perigee . . . of approximately 500 nautical miles could be equipped with a compact escape capsule capable of safely returning a man to the earth's surface from any point in the satellite's trajectory or orbit. This could be accomplished with what we know today . . . . "

Crew Escape From Space Vehicles— and Survival

Hugo F. Mohrlock and Earl A. Kops
Convair (San Diego)
A Division of General Dynamics Corporation

THE SAFETY of today's aircraft is impressive when compared with that of the early "kites" that first lifted man into powered flight 50 years ago. Those early pioneers, however, were more concerned with performance than with safety. This, of course, was a necessity, for, if the early "birds" had been saddled with a heavy escape system, they simply would not have gotten off the ground.

It was long after the development of the airplane itself that the pilot was first provided with a parachute as a means of escape from his disabled craft. If failures occurred, the pilot could stay with the aircraft and usually make a safe emergency landing.

Space Escape Difficulties

Beyond the atmosphere, an unusual set of requirements prevail for escape and survival. In space, staying with the parent vehicle will not assure you of a safe return to earth if the craft becomes disabled. As an example, a trip to Venus, which would take 145 days on the most economical path, would require power application at the beginning and again at the end of the journey in order to match speed with the orbital speed of Venus. (Another small application of power at mid-journey would be required to correct for the inclination of the orbit of Venus with the earth's orbit.) If the power plant failed when speed matching was required, the spacecraft would pass Venus and swing back toward the earth's orbit, and 290 days after departure would be back to its point of origin. Unfortunately, by that time the earth would be far away from this point in its orbit. The spacecraft would continue in its elliptical orbit five times around the sun before it came near the earth again—a process that would take 4 years.

Proposed Methods of Rescue

Two basic methods of space rescue have been considered—one, to provide rescue by another vehicle; the other, to provide an independent escape vehicle within the spacecraft.

To launch a rescue vehicle successfully, effect a rescue, and return to earth would require at least the following:

(1) Development of a Space Guard (much like the present Coast Guard).

(2) Capability of signalling an S.O.S. (a disabled craft might be incapable of this).

(3) A spacecraft still sufficiently intact to permit survival until the rescue vehicle arrived.

(4) An extremely precise technique of tracking and intercepting the disabled craft.

(5) Time to complete a rescue (it could take months, even years).

Considering all these factors, an attempt to rescue the crew from a disabled spacecraft in some remote section of the solar system begins to appear hopeless.

Hugo Mohrlock has recently been promoted to Assistant Project Engineer (Design and Development) in the F-106 Project Office at Convair (San Diego). In his former capacity of Design Group Engineer, he was in charge of the Convair design assignment when that company was chairman of the Industry Crew Escape Systems Committee to develop an upward ejection system. Having been active in designing these systems during the last 8 years, he has turned his attention in this article toward space escape and the difficulties it will present.

Twenty years' experience in the aircraft industry has provided Earl Kops, Engineering Design Specialist at Convair (San Diego), with the background for coauthoring this article on space escape. During the last 5 years, Kops has worked on pilot escape systems, seats, and survival equipment for advanced aircraft and space vehicles. Prior to joining the Furnishings Group, he was with the Engineering Test Laboratories where he was in charge of conducting escape system tests and sled testing. During the early development of the Atlas missile, Kops was in charge of that missile's fuel, oxidizer, and pressurization systems tests.

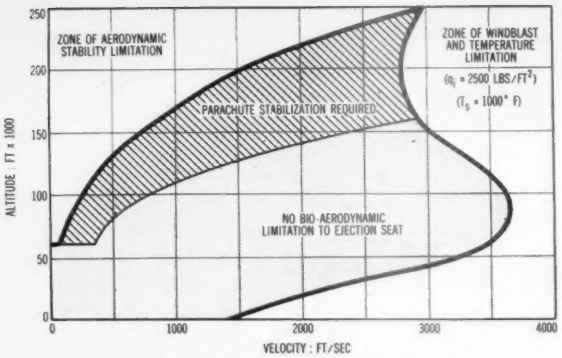

FIG. 1. Performance envelope of ICESC "B" seat.

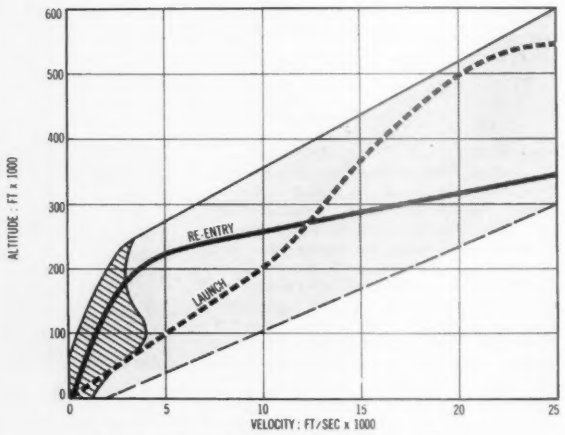

FIG. 2. Extended envelope for space flight.

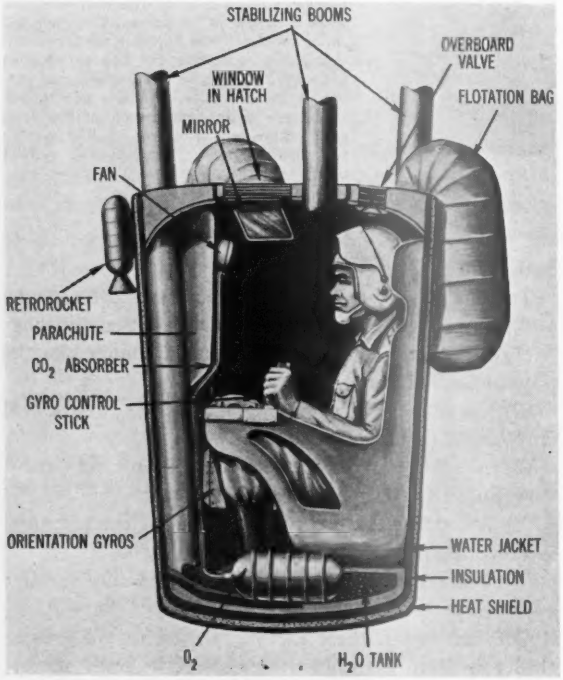

FIG. 3. Sectional view of escape vehicle.

And even in the event that someday space rescue does become feasible, we will still need an independent escape vehicle to provide crew protection for drastic spaceship failures.

Thus, it is apparent that each spaceship should be self sufficient in terms of meeting space emergencies. The solution is an escape vehicle—a "spaceship within a spaceship."

Such a vehicle must provide propulsion means to permit kinematic energy changes. Without this, it might become a permanent satellite or continue off in space as a man-made asteroid destined to circuit the sun. Kinematic energy changes are not confined solely to changing orbits to permit falling toward some nearby planet. Assuming the escape vehicle has been propelled into a revised space vector to intercept a habitable planet, preferably the earth, means must be provided for dissipating the intercept energy prior to ground contact, for the energy involved in bringing an object back from space is equal to that involved in putting it there in the first place. Fantastically large amounts of energy may be involved.

Rocket propulsion as we know it today is far too inefficient to permit burdening a space vehicle with an escape system equal in performance to the parent vehicle itself, although development of new propulsive means such as atomic power may take care of this in the near future.

The many problems of crew escape and rescue far out in space constitute a curious and fascinating subject, though to go into it deeply would require much more space than this article permits. It seems opportune at this point to mention that crew escape provisions are not necessarily required only for emergency escape from a disabled parent craft. Return of an individual crewman to the earth may be required, as an example, for medical care. In addition, when the mission of the spacecraft crew has been completed, it would be economically desirable to return the crew and allow the parent craft to remain in orbit around the earth. It would be possible in this manner to create a space "stock-orbit" of miscellaneous vehicles and equipment for the use of future space travelers.

Man's early flights into space will no doubt be by minimum energy rocket orbits comparable to the satellites already launched from the earth. Let us, therefore, consider the problems concerned with this elementary space flight, and study an escape system to serve this particular situation. The Industry Crew Escape Systems Committee (ICESC) "B" seat developed by Convair (San Diego) is presently capable of performance at dynamic pressures up to 2,500 lbs./ft.^{2}. While this is certainly not its maximum potential, this value was used as one of the performance envelope limits for Fig. 1. Admittedly this envelope is somewhat arbitrary and conservative, but, when we compare it with the hypothetical spacecraft mission profile of Fig. 2, we realize that conservatism in the seat envelope is of little real significance. In the earth's

atmosphere, an escape vehicle capable of much greater performance is certainly required.

The Miniature Escape Vehicle

A manned earth satellite having a perigee (closest approach) of approximately 500 nautical miles could be equipped with a compact escape capsule capable of safely returning a man to the earth's surface from any point in the satellite's trajectory or orbit. This could be accomplished with what we know today, and one of these capsules would be provided for each crew member. The parent vehicle or spaceship could incorporate these escape capsules in flush-type wells or as appendages if external cleanness is unimportant. Several of the features of the ICESC "B" seat which was mentioned above have been retained in the new escape vehicle, the foremost being the rocket for changing our space vector and the stabilizing booms which compare to the stabilizing stick on a 4th of July skyrocket. These booms, shown in Fig. 3, provide excellent stability over an extended speed range.

Separation from the parent vehicle would be by ballistic charges to actuate a disconnect and impart a small separation velocity. Immediately upon separation, the stabilizing booms will automatically extend (ballistically powered) and the stabilizing gyros will be accelerated up to speed. Two gyros are planned and will be mounted parallel and rotated oppositely up to full r.p.m. thus imparting no reactions on the escape capsule. When at full r.p.m., the two gyros will be rotated relatively to a 90-deg. skewed axis relationship. This gyro package can resist rotational forces applied and can thereby bring the capsule to a stationary nontumbling attitude. The occupant can then orient the capsule to any desired attitude by these same gyros.

A small amount of rocket power directed properly to alter the orbit of the escape vehicle could drop the perigee into the atmosphere sufficiently so that aerodynamic drag would dissipate the orbital energy. Retrorocketing to slow down the capsule should be accomplished at apogee to permit antipodal entry into the atmosphere at perigee. Hypergolic rocket fuels would be used to permit intermittent rocket operation. After orienting the capsule for retrorocketing, a short rocket burst would be applied to test the rocket direction. If the thrust was not sufficiently close to the c.g., an attitude change would result. The occupant could adjust for rocket direction and test again. When the thrust direction is close enough through the c.g. that the gyros maintain the proper attitude to the capsule, the balance of the rocket thrust can be applied. An escape vehicle 500 nautical miles above the earth at perigee requires less than 1/3 g deceleration for 70 sec. (at apogee) to initiate re-entry from orbit. If we assume an escape vehicle gross weight of 600 lbs., this power could be provided for less than 60 lbs.

A period of waiting follows until perigee is reached. The occupant orients the vehicle for entry into the atmosphere and deploys a small drag chute. This drag chute will supply directional stability in the rarified upper atmosphere until dynamic pressure builds up to the point at which the stabilizing booms are effective.

Once we have entered the earth's atmosphere, the aerodynamic drag will accomplish the remaining deceleration. The objective in this phase is to reject the heat into the atmosphere rather than absorb or dissipate it. By providing a thin heat shield (thereby a small heat sink), stabilization temperatures will be quickly reached and further heating will be imparted to the impinging and ambient air. Immediately inside the heat shield is a substantial insulator, and inside this is a thin water jacket. The small amount of heat that does pass inward is dissipated by boiling the jacketed water. Temperature is controlled by regulating the boil-off pressure. Local hot spots (corner of the forward face of the heat shield) will be reinforced with ablating material to ensure overall shield integrity. The small drag chute deployed prior to entering the atmosphere will burn off during this heating phase. However, the stainless steel booms will provide directional stability until the main parachute is deployed.

FIG. 4. Re-entry and recovery sequence.

Deceleration during the prolonged aerodynamic drag phase will not induce excessive accelerations on the occupant if proper body positioning and support are provided. In addition to providing a full body contour support, the occupant will be provided with an anti-*g* suit, automatically controlled for varying accelerations. Some new and quite novel *g* suits have been devised and would provide protection for accelerations many times as severe as our occupant will experience.

In the final phase of re-entry and descent to the earth's surface, a terminal velocity of less than 200 m.p.h. indicated airspeed is attained. Deployment of the main parachute is automatically instigated at 20,000 ft. altitude. Velocity at impact with the ground or water is estimated to be 25 ft. per sec. A reserve parachute for landing is provided and simply supplements the main parachute in the event of its failure.

It is most probable that a landing would occur in water, and ultimate rescue would be dependent on survival for several hours or perhaps days. Flotation bags are provided and can be inflated by a CO_2 bottle or by a hand pump. With the bags inflated, the occupant can open the hatch and climb out, or he can open an air vent and remain essentially sealed in. A small emergency radio or beacon would be provided to aid rescue.

The sequence of events as described originated from a satellite while in orbit. Equally successful crew escape can be accomplished during any other phase of the satellite's mission, including the initial part of the launch.

Conclusion

While it is not intended to launch a manned space vehicle wherein safety is a question, nevertheless each beginning into a new era involves hazards. With this in mind, we have attempted to develop a method of rescue suitable for these early orbital ventures. The "pocket-sized spaceship" seems to be the most feasible answer to the problem of bringing man safely back to earth from a spacecraft.

✦ ✦ ✦

Technical Management *(Continued from page 78)*

clouds. For inspiration we have the funnies, Jules Verne, science fiction, and other worthy publications. Not so long ago, before we suspected the existence of a dangerous layer of radiation, many—not only science fiction writers but some experts—pushed very hard for a missile-firing station on the moon. This type of imagination can only be detrimental; it shows the area where we can fritter away hundreds of millions of dollars and the valuable time of irreplaceable expert talent. It looks as if the saying "Why make it simple, if you can make it complicated?" is gaining headway.

We know quite a bit about missiles by now, and our technical competence has greatly improved by our understanding the problems better. I hope we do not go down the same painful road of experience when we design space vehicles. It seems at this moment that we have not learned too much. The picture is not too encouraging since every little group of interests has its own specific solution. Enthusiasm is a fine thing if it is backed by knowledge and sound judgment.

Some are going to use the stars for reference, some must have gyros when traveling in space—just as a number of pet solutions exist for re-entry problems.

In closing, I would like to suggest that we make more of an effort to know the problems better. Let us do more and better research work this time, and pay attention to details.

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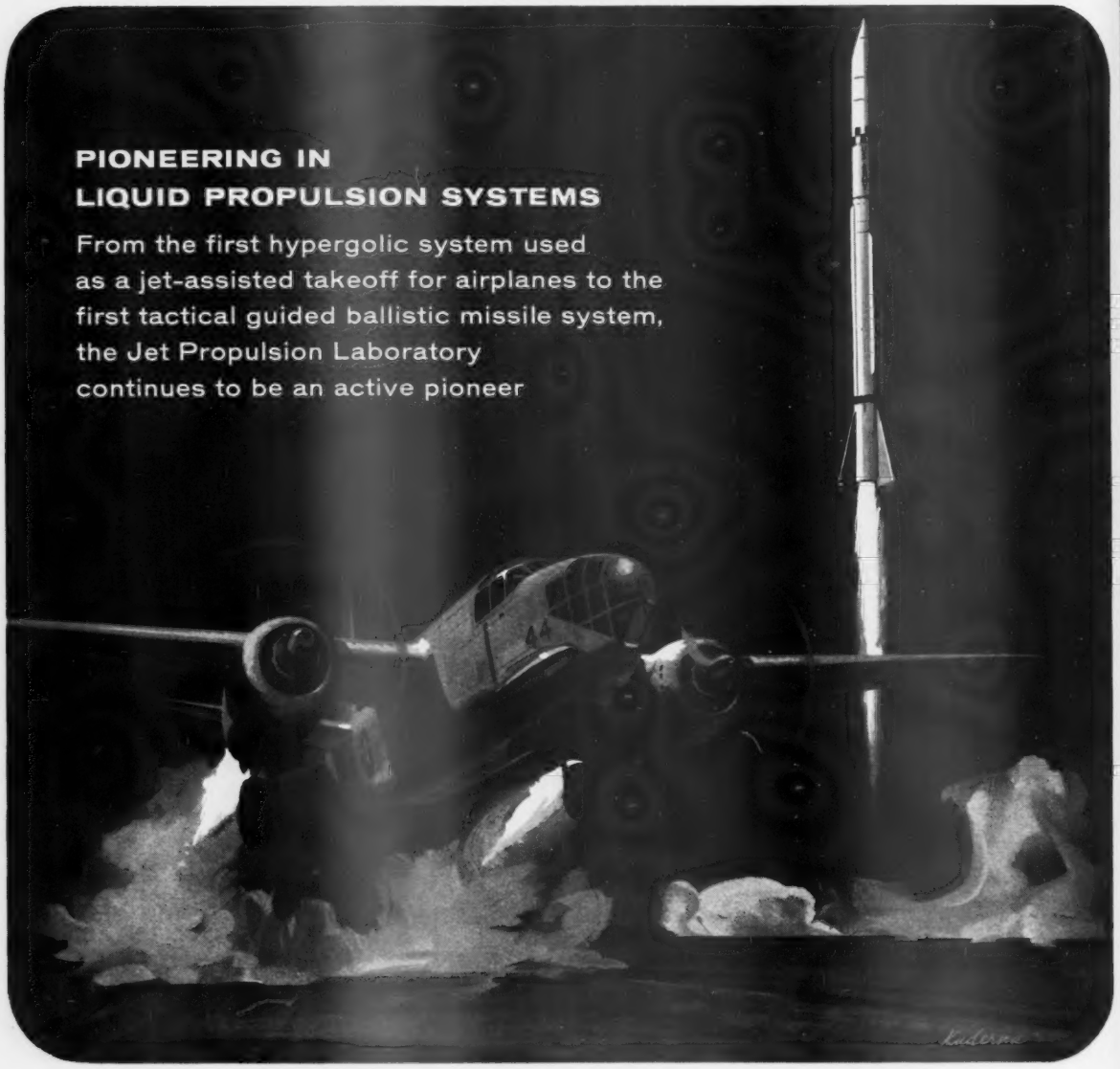

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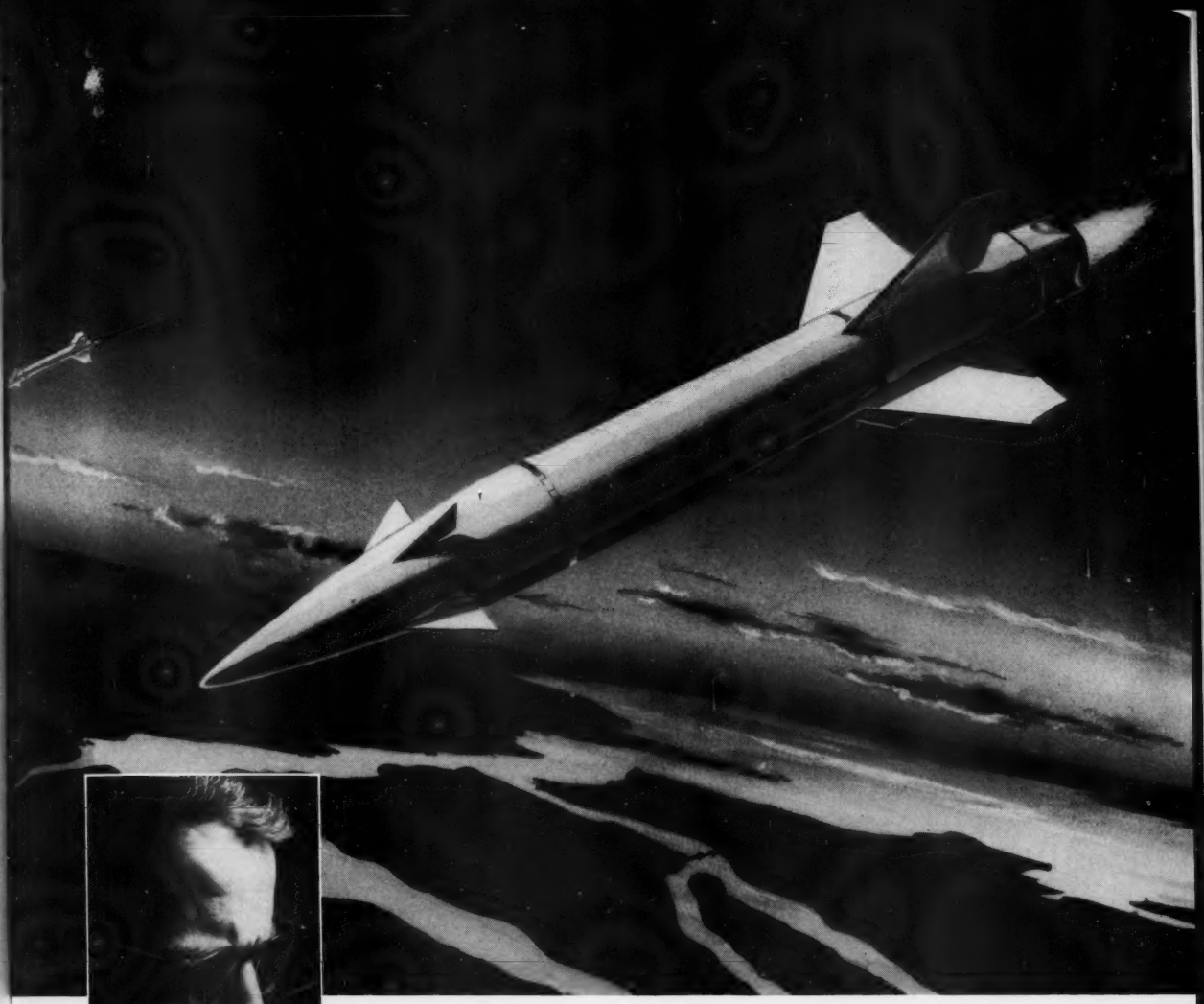

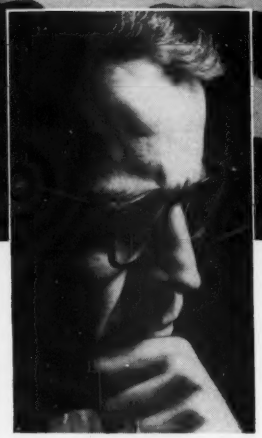

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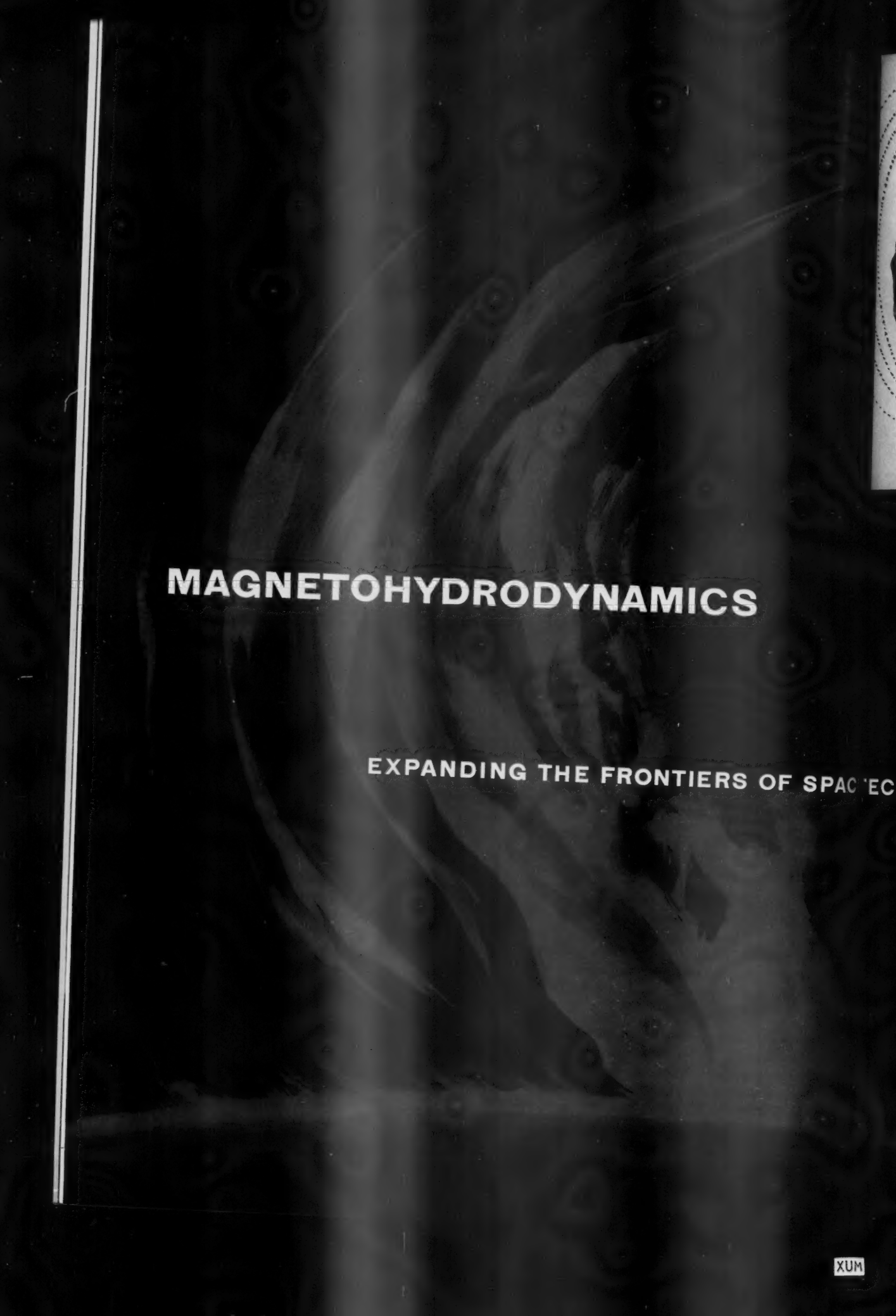

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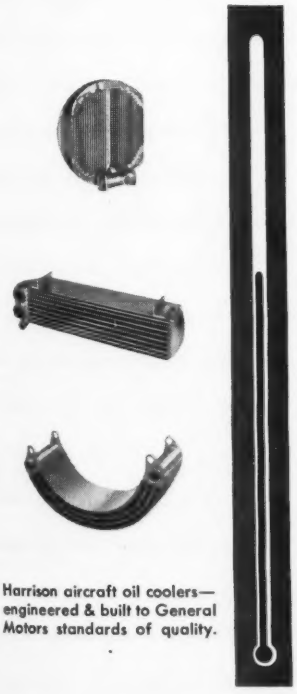

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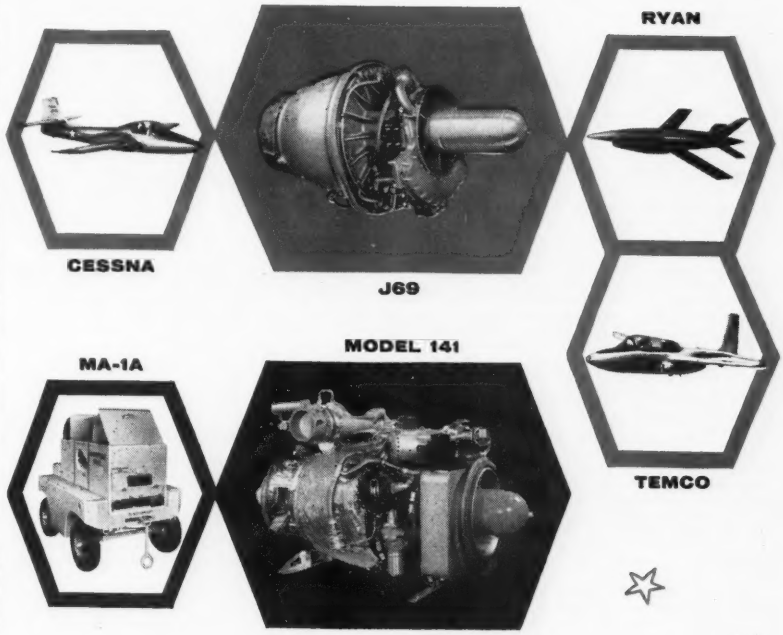

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New Cleanliness Standards Required for Handling Gas Turbine Fuels. Colin Campbell. *Can. Aircraft Ind.*, Dec., 1958, pp. 4, 5, 30–33. Discussion on proper filtration, fuel handling equipment, and methods to increase the life of fuel system components and the safety of flight operations.

Solid Propellant Aging. N. Fishman. *Ordnance*, Jan.-Feb., 1959, pp. 681–683. Discussion of the effects of storage ageing on the reliability of a rocket.

Application of Surface Decomposition Kinetics to Detonation of Ammonium Nitrate. W. H. Andersen and R. F. Chaiken. *ARS J.*, Jan., 1959, pp. 49–51. 12 refs. AFOSR-supported calculation of the detonation reaction time for ammonium nitrate using the kinetic rate data for linear surface gasification in conjunction with the Eyring grain burning theory. A new grain burning mechanism is postulated.

A Ballistic Bomb Method for Determining the Experimental Performance of Rocket Propellants. D. N. Griffin, Ch. F. Turner, and G. T. Angeloff. *ARS J.*, Jan., 1959, pp. 15–19. Development of a method which allows performance evaluation at an early stage when only limited quantities of a new propellant are available.

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A Radioactive Ionization Gage Pressure Measurement System. N. W. Spencer and R. L. Boggess. *ARS J.*, Jan., 1959, pp. 68–71.

Flight Instruments

Response, Accuracy and Display Requirements for Take-Off Monitors. Appendix—**Influence of Instrumentation Accuracy on Go-No Go System Performance.** R. P. Snodgrass. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-76.* 27 pp. Members, $0.50; nonmembers, $1.00. Analysis of the take off and the problem of monitoring aircraft performance during take off; the question of refusal is stressed. The effects of wind, water on the runway, response-accuracy, and human factors requirements are considered.

Gyroscopes

Some Effects of Vibration and Rotation on the Drift of Gyroscopic Instruments. R. M. Stewart. (*ARS Semi-Annual Meeting, Los Angeles, June 9–12, 1958.*) *ARS J.*, Jan., 1959, pp. 22–28. Description of possible analytical approaches to some significant mechanisms by which vibration-induced drifts may occur, and presentation of some means of alleviating them.

Zatukhanie Sobstvennykh Kolebanii Giroskopa v Kardanovom Podvese s Sukhim Treniem. D. M. Klimov. *AN SSSR Dokl.*, Nov. 21, 1958, pp. 410–412. In Russian. Study of the motion of a stabilized gyroscope on a gimbal support with dry friction in order to calculate the damping of natural vibrations.

Panels & Dials

Building Light Into Instruments for Daylight and Night Vision. V. A. Orlando and J. J. Fraizer. *Mach. Des.*, Jan. 8, 1959, pp. 118–123. Discussion of the advantages of built-in lights and of the various lighting assembly parts. Light balancing and design problems due to heat are described.

Temperature Measuring Devices

A Thermometer for High-Speed Aircraft. D. D. Clark. *J. Sci. Instr.*, Dec., 1958, pp. 433–439. 17 refs. Derivation of the principles of aircraft thermometer design. Its construction and application to supersonic flight are described. Wind-tunnel test results are discussed, and lag and radiation errors are calculated.

Lighter-Than-Air

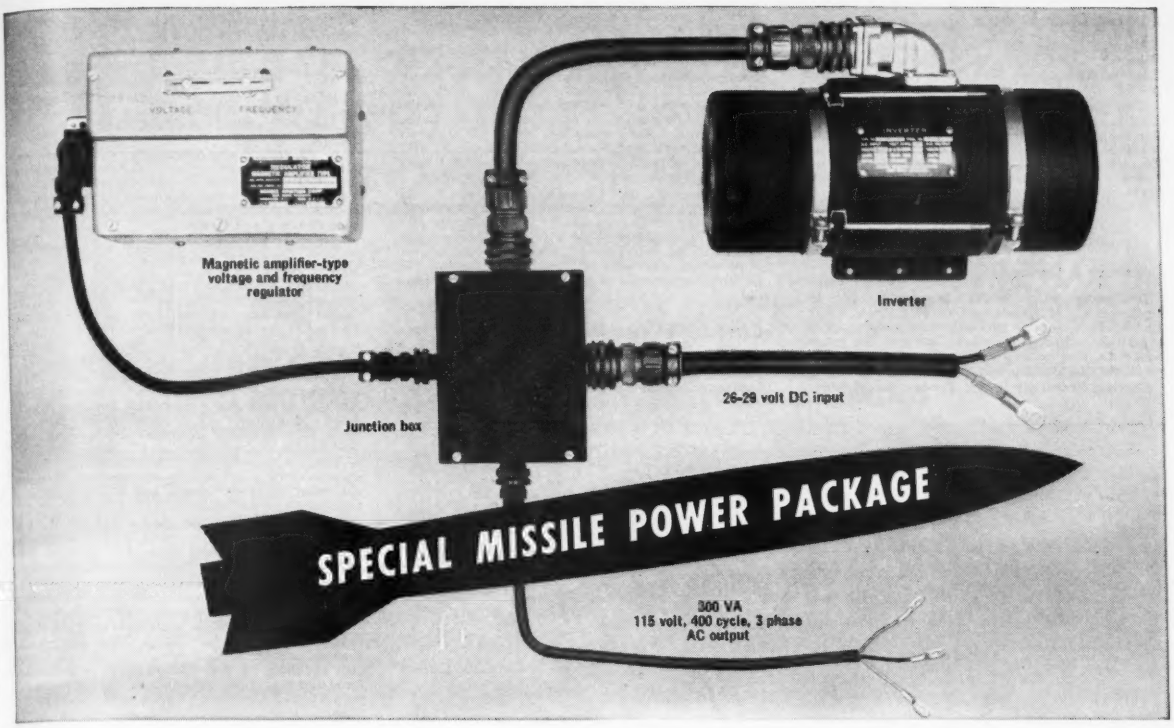
High-Altitude Nighttime Balloons. Moses Sharenow. *AMS Bul.*, Dec., 1958, pp. 648–651. Development of a balloon capable of attaining a bursting altitude of 100,000 ft. and suitable for tests in both tropical and temperature latitudes.

Non-Rigid Airships. John Kevern. *Aircraft & Missiles Mfg.*, Jan., 1959, pp. 34–37. Survey of design and construction details stressing the importance of weight distribution.

Machine Elements

Bearings

A Second Approximation Solution on the Elastic Contact Problem. Loo Tsu-Tao. *Scientia Sinica*, Dec., 1958, pp. 1,235–1,246. Presentation of a solution for the pressure distribution between two elastic bodies in contact. The theory contains the next higher order terms of its Taylor series expansion, in addition to the terms used by Hertz. The applicability of the theory is illustrated on a specific case.



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32B81	27.5	100	115/200	3	1500	Unlimited	65	—
32B77	27.5	180	115/200	3	3000	Unlimited	75	—
32B79	27.5	400	115/200	3	7000	Unlimited	115	—
32B76	27.5	20	115	3	500	70,000	25	—
32B122	27.5	150	115/200	3	2500	50,000	65	—
32B41	27.5	150	115/200	1 3	2500 3000	50,000	68	—
32B52	27.5	35	115/200	1 3	500 500	40,000	25	—
32B106	27.5	95	115	3	1400	35,000	44	—
32B27	27.5	285	115/200	1 3	3500 4000	50,000	76	—

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12126	27.5	2	26	3	10	35,000	2.3	E1615
MG-54	27.5	22	115/200	1 3	250 250	50,000	17	E5109
12142	27.5	22	115	1 3	250 250	35,000	13	E1617
12143	27.5	22	115	3	250	35,000	13	—
32E01	27.5	35	115	3	500	50,000	26	AN3533-1
32E00	27.5	51	115	1 3	500 750	50,000	34	AN3534-1
MG-65	27.5	52	115/200	1 3	750 750	50,000	35	E52805-2
MG-61	27.5	126	115	1	1750	50,000	54	53C6767
1518	27.5	126	115	1 3	1500 1800	20,000	37	—
32E06	27.5	160	115/200	1 3	2000 2250	50,000	56	E1725
32E03-3	27.5	150	115	1	2500	50,000	58	53B6227
32E03-9	27.5	160	115/200	1 3	2500 3000	50,000	58	E54807
32E09	27.5	160	115	1 3	2500 3000	50,000	60	—

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Rotating Discs & Shafts

Plastic Design of Rotating Discs. Jacques Heyman. *IME Proc.*, No. 14, 1959, pp. 531–541; Communications, pp. 542–547; Author's Reply, p. 547. 17 refs.

The Coaxial Circular Disc Problem. J. C. Cooke. *ZAMM*, Sept.-Oct., 1958, pp. 349–356. Presentation of a semiempirical method used to complement Maxwell's approximate calculation. The case of a disc rotating slowly in a coaxial cylinder filled with viscous fluid is treated as an example.

Materials

Ceramics & Ceramals

Designing with Brittle Materials. W. H. Duckworth. *Materials in Des. Eng.*, Jan., 1959, pp. 82–85. Discussion on the importance of adjusting component design, interpreting property data, and getting optimum material quality for successful mechanical design.

Current Problems in the Production of Magnetic Ceramics. George Economos. *MIT LIR TR 131*, Nov., 1958. 7 pp.

Measurements of Total Hemispherical Emissivity of Several Stably Oxidized Metals and Some Refractory Oxide Coatings. W. R. Wade. *U.S., NASA Memo. 1-20-59L*, Jan., 1959. 30 pp. Description of the apparatus and methods used, and presentation of experimental results. The metals tested included type 347 stainless steel, tungsten, and Haynes alloys B, C, X, and 25. The refractory oxide coatings were flame-sprayed alumina and zirconia.

New Aspects in Ceramic Coatings. P. A. Huppert. (*ASME-ARS Av. Conf., Dallas, Mar. 17–20, 1958.*) *ARS J.*, Jan., 1959, pp. 19–21. 10 refs. Description of recent achievements in modifying conventional ceramic coatings and application techniques, and discussion of lithium compounds as prime modifying constituents.

Corrosion & Protective Coatings

Corrosion Tests with Experimental Chromate-Pigmented Jointing Compounds. Appendix—Limits of Composition of Metallic Materials. E. G. Savage and H. G. Cole. *Gt. Brit., RAE, TN Met. 291*, July, 1958. 14 pp.

High Temperature

Effect of a Ceramic Coating on the Creep Behavior of Some High-Temperature Alloys. J. R. Cuthill, J. C. Richmond, and N. J. Tighe. (*Am. Ceram. Soc. 58th Annual Meeting, New York, Apr. 23, 1956.*) *Am. Ceram. Soc. Bul.*, Jan., 1959, pp. 4–12. 14 refs. Experimental investigation showing that ceramic coating markedly decreases the creep or extension in most cases, but has a detrimental effect at certain combinations of temperature and stress.

Aliajele Refractare Folosite în Construcția Turboreactoarelor de Aviație. Pascal Popescu and Constantin Mincu. *Rev. Transp.*, Oct., 1958, pp. 513–520. 14 refs. In Rumanian. Outline of working conditions and temperature requirements for main parts of jet power plants, as well as survey of refractory alloys used.

Metals & Alloys

Issledovanie K β-Gruppy Rentgenovskogo Spektra Margantsa v Splavakh Sistemy Mn-Ni. V. A. Kazantsev. *AN SSSR Dokl.*, Nov. 21, 1958, pp. 449–452. 10 refs. In Russian. Investigation of the K β-group of manganese X-ray spectra in alloys of the Mn-Ni system. Experimental results include the composition of alloys, the effect of temperature, and the transition to the paramagnetic state.

Issledovanie Sistemy SnTe-GeTe. N. Kh. Abrikosov, A. M. Vasserman, and L. V. Poretskaia. *AN SSSR Dokl.*, Nov. 11, 1958, pp. 279–281. 12 refs. In Russian. Experimental study of the behavior of ternary systems Sn-Ge-Te, covering microhardness tests and thermal analysis.

Termodinamicheskie Svoistva Tverdykh Rastvorov Cu-Ni i Fe-Co. Ia. I. Gerasimov, A. A. Vecher, and V. A. Geiderikh. *AN SSSR Dokl.*, Oct. 11, 1958, pp. 834–836. 11 refs. In Russian. Experimental determination of thermodynamic properties of Cu-Ni and Fe-Co solid solutions.

Mach 3 Metal. *Ryan Reporter*, Oct. 10, 1958, pp. 9–11, 26. Development of a corrugated stainless-steel sheet for high-temperature structural purposes.

Metals & Alloys, Nonferrous

Premières Micrographies Optiques Montrant les Sources Multiplicatrices de Dislocations dans l'Alliage Aluminium-Cuivre à 4%. P. A. Jacquet. *La Recherche Aéronautique*, Nov.-Dec., 1958, pp. 53, 54. In French. Presentation of experimental results on multiplicative dislocation sources for Al-Cu (4 per cent) alloys obtained by means of optical micrography.

A Status Report on Heat, Wear and Corrosion Resistant Molybdenum Coatings. H. W. Schultze, R. R. Freeman, and J. Z. Briggs. *Materials in Des. Eng.*, Jan., 1959, pp. 76–81. Discussion of the properties and use of molybdenum coatings. The latest information on application techniques is summarized.

A Study of the Grain Boundary Reaction of Mg-Al Alloys. Ryoji Watanable and Shigeyasu Koda. *Hokkaido Gakugei U. J., Sect. B*, Dec., 1957, pp. 65–77. 17 refs. In Japanese. Study of the grain boundary reaction phenomena of Mg-Al alloys containing 7.02, 8.87, and 10.74 per cent Al, respectively. The rate of growth of nodules of the grain boundary reaction is obtained and the characteristics of the reaction are investigated.

Lithium, a Promising Alloying Element. P. D. Frost. *Battelle Tech. Rev.*, Jan., 1959, pp. 3–8. Discussion of the promising values of lithium as an alloying element and of the factors affecting its future use. The usefulness of lithium alloys for structural and nuclear-energy applications is described.

Magnesium Forgings Save Weight. L. E. Wilensky. *Materials in Des. Eng.*, Jan., 1959, pp. 92–94. Discussion of the advantages and application of magnesium forgings; design suggestions are made.

Slope Casting Test Results on Some Established and Experimental Magnesium Casting Alloys. D. J. Whitehead. *Light Metals*, Dec., 1958, pp. 391–395. Investigation covering such factors as the influence of section thickness and imperfect feeding conditions on the incidence of microporosity and tensile properties. Test results are presented and discussed.

Nonmetallic Materials

Properties of Foams and Laminates Under Shock Loading. R. H. Supnik and Melvin Silberberg. *SPE J.*, Jan., 1959, pp. 43–47.

The Choice of Resilient Materials for Anti-Vibration Mountings. J. C. Snowdon. *Brit. J. Appl. Phys.*, Dec., 1958, pp. 461–469. 12 refs. Development of criteria to define good anti-vibration mount material. It is concluded that such a material should possess a high damping factor which does not increase greatly with fre-

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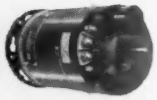

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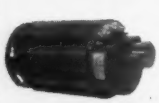

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ACOUSTICS, SOUND, NOISE

STATISTICAL EVALUATION OF NEAR-FIELD SOUND PRESSURES GENERATED BY THE EXHAUST OF A HIGH-PERFORMANCE JET ENGINE. E. C. Kamps. ASA J., Jan., 1959, pp. 65-67. Study concerned with the establishment of the level and the rate of occurrence of peak pressures in relation to the commonly measured r.m.s. level. A method is presented which enables the determination of these qualities from r.m.s. sound pressures recorded on magnetic tape. Also included are typical results obtained from near-field sound pressures generated by the jet exhaust of a G-E CJ805 engine. Results indicate that (1) occurrence of peak pressures does not follow a Rayleigh distribution, (2) peak pressure distribution is not altered by the physical position related to the jet stream nor does it appear to be a function of frequency, (3) a maximum ratio of peak to r.m.s. pressure is shown to exceed four.

THE VIBRATIONS OF A THIN-WALLED STIFFENED CYLINDER IN AN ACOUSTIC FIELD. Appendix - DETAILS OF THE CALCULATION FOR THE PLANE WAVE EXCITATION OF THE STIFFENED CYLINDER. J. H. Foxwell and R. E. Franklin. Aero. Quart., Feb., 1959, pp. 47-64. 10 refs. Calculation of the modes of vibration of a structure, taking into account the surrounding medium. A two-dimensional problem is considered, covering an infinitely long stiffened cylinder in a field of plane simple harmonic sound waves, the wave fronts of which lie in a plane which is parallel to the plane formed by the cylinder axis and a cylinder generator. The displacements may be represented by a Fourier series, each term corresponding to a mode of deformation and the coefficients to the generalized Lagrangian coordinates.

AERODYNAMICS, FLUID MECHANICS

Aerothermodynamics

ON THE APPLICATION OF LIEPMANN'S HEAT TRANSFER FORMULA. R. M. Mark. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 155-164. Calculation of the skin friction, using an approximate expression for the total enthalpy, for the case of high Mach Number flows with nonuniform pressure distributions on nonisothermal surfaces. The heat transfer distribution is then calculated by means of Liepmann's heat transfer formula. The comparison of the approximate results with exact solutions shows that the present simplified method yields results that are within engineering tolerances.

INFLUENZA DEL TRASPORTO DI MASSA SUL COEFFICIENTE DI CONVEZIONE. III - STRATO-LIMITE-TERMICO CON ASPIRAZIONE, IN REGIME LAMINARE, PER FLUIDI A NUMERO DI PRANDTL $\leq$ 1. Giuseppe Trapanese. L'Aerotecnica, Oct., 1958, pp. 285-292. 12 refs. In Italian. Analysis covering the influence of condensation at Prandtl Numbers $\leq$ 1 on the boundary layer of a flat plate. The variation of the local thermal convection coefficient h with Prandtl Number and condensation is discussed. The convection coefficient can be deduced as a function of the known parameters by means of appropriate diagrams. Includes a comparison of theoretical results with those obtained experimentally.

AXISYMMETRIC STAGNATION POINT MASS-TRANSFER COOLING. H. Hoshizaki and H. J. Smith. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 45-114. 12 refs. Analysis of the effect of helium injection into the boundary layer in the vicinity of an axisymmetric stagnation point. Helium was chosen as the coolant because of its high heat capacity. The fluid properties are assumed to be functions of both the mixture temperature and the concentration of the foreign gas. For simplicity, the boundary layer is considered to be a "binary mixture" of helium and dissociated air. The diffusion of oxygen and nitrogen atoms is neglected, although the thermal and transport properties used for air are dissociated equilibrium values. Velocity, temperature, and helium concentration profiles in the boundary layer are presented for various stagnation pressures, stagnation temperatures, wall cooling ra-

tios, and mass injection rates. Design curves which enable the designer to determine the injection rate necessary to maintain a specified wall temperature are also presented.

SOME FINITE DIFFERENCE SOLUTIONS OF THE LAMINAR COMPRESSIBLE BOUNDARY LAYER SHOWING THE EFFECTS OF UPSTREAM TRANSPIRATION COOLING. Appendix A - MATHEMATICAL DESCRIPTION OF THE SOLUTION. Appendix B - THE FINITE DIFFERENCE SOLUTION AND THE RUBESIN AND INOUYE THERMAL ANALYSIS. Appendix C - COMPUTER PROGRAM MODIFICATIONS. J. T. Howe. US, NASA Memo. 2-26-59A, Feb., 1959. 33 pp. 12 refs. Application of the finite difference method to the derivation of three numerical solutions of the partial differential equations describing the laminar boundary layer. The solutions apply to steady-state supersonic flow without pressure gradient, (a) over a cold wall and over an adiabatic wall, both having transpiration cooling upstream, and (b) over an adiabatic wall with upstream cooling but without upstream transpiration. It is shown that, for a given upstream wall temperature, upstream transpiration cooling affords much better protection to the adiabatic solid wall than does upstream cooling without transpiration. A comparison of the results of numerical solutions with those of approximate solutions is made.

THE EFFECT OF VEHICLE DECELERATION ON A MELTING SURFACE. D. M. Tellep. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 115-154. 11 refs. Analysis of the characteristics of a molten layer when subjected to deceleration forces. Pyrex glass is chosen as an example; numerical solutions based upon a similarity transform are provided, and approximate analytic solutions are obtained. It is found that deceleration tends to thicken the film, increase the interface temperature, and reduce the melting rate. Reverse flow occurs in portions of the film for sufficiently high decelerations, and an approximate expression is obtained for predicting the magnitude of the deceleration which causes reverse flow. The overall effect of deceleration, taking into account the coupling between the gaseous and liquid boundary layers, is discussed.

ÜBERTRAGUNG DER GÖRTLER'SCHEN REIHE AUF DIE BERECHNUNG VON TEMPERATURGRENZSCHICHTEN. I. E. Wrage. DVL Bericht No. 81, Dec., 1958. 45 pp. 12 refs. Westdeutscher Verlag, Köln & Opladen. In German. Application of Görtler series for determining the velocity fields to the calculation of thermal boundary layers. The universal functions for calculating the temperature field can be used in case of the thermometer problem for given variable wall temperature, as well as for given mixed boundary layers at the wall.

THE MELTING OF FINITE SLABS. T. R. Goodman and J. J. Shea. Allied Res. Assoc. (AFOSR TN 58-824) [AD 202908], Aug. 15, 1958. 40 pp. Development of an approximate method, known as the heat balance integral, to determine the melting rate of a finite slab which is initially at a uniform temperature below the melting point. The slab is acted upon by a constant heat input at one face and has its other face either insulated or kept at its initial temperature. The first three terms of series solutions in an intrinsically small parameter are obtained for the time histories of melting and temperature distribution in the slabs.

Boundary Layer

AN EQUATION FOR THE MEAN VELOCITY DISTRIBUTION OF BOUNDARY LAYERS. V. A. Sandborn. US, NASA Memo. 2-5-59E, Feb., 1959. 47 pp. 25 refs. Development of a general relation, empirical in origin, for the mean velocity distribution of both laminar and turbulent boundary layers. The equation, in general, accurately describes the profiles in both laminar and turbulent flows. The calculation of profiles is based on a prior knowledge of momentum, displacement, and boundary-layer thickness together with free-stream conditions. For the inner or turbulent boundary layers the present relation agrees very closely with experimental measurements even in cases where logarithmic law of the wall is inadequate. A unique relation between profile form factors and the ratio of displacement thickness is obtained for turbulent separation. A similar criterion is also obtained for laminar separation. These relations are demonstrated to serve as an accurate criterion for identifying separation in known profiles.

DAS VERHALTEN DER DREIDIMENSIONALEN, LAMINAREN GRENZSCHICHTSTRÖMUNG BEI ZUNEHMENDEN ANSTELLWINKELN. J. A. Zaat. Netherlands, NLL TN F. 215, Oct. 5, 1958. 27 pp. In German. Investigation of the behavior of three-dimensional laminar boundary layers with increasing incidence. The applicability of a simplified method, based on momentum equations in streamline coordinates, is demonstrated. The boundary layer is calculated for a yawed cylinder at angles of incidence of 6° and 12°, and the numerical results are evaluated.

BOUNDARY-LAYER TRANSITION ON HOLLOW CYLINDERS IN SUPERSONIC FREE FLIGHT AS AFFECTED BY MACH NUMBER AND A SCREW-THREAD TYPE OF SURFACE ROUGHNESS. C. S. James. US, NASA Memo. 1-20-59A, Feb., 1959. 49 pp. 31 refs. Results of tests conducted over a Mach Number range from 2.8 to 7.0 at a nominally constant Reynolds Number of 3 million per in. Transition Reynolds Number is found to increase with increasing Mach Number at a rate depending simultaneously on Mach Number and roughness height. The laminar boundary layer is found to tolerate increasing amounts of roughness as Mach Number increases. For a given Mach Number an optimum roughness height is found which gives a maximum laminar run greater than that obtained with a smooth surface.

THE SMALLEST HEIGHT OF ROUGHNESS CAPABLE OF AFFECTING BOUNDARY-LAYER

TRANSITION. Appendix - AN IMPROVED PHYSICAL MODEL FOR THE COMPRESSIBLE FLOW PAST AN ISOLATED BIT OF ROUGHNESS. A. M. O. Smith and D. W. Clutter. J. Aero/Space Sci., Apr., 1959, pp. 229-245, 256. 39 refs. Extension of a previous investigation covering critical roughness in low-speed flow to include the effects of high Mach Number. Analysis of the available data on critical roughness in supersonic flow indicates that roughness (as in subsonic flow) may still be correlated by the roughness Reynolds Number. The value of this Reynolds Number depends primarily on the Mach Number at the top of the roughness. When this Mach Number is greater than one, the roughness Reynolds Number, based on conditions behind the shock, is probably the characteristic parameter. A third method for calculating the roughness Reynolds Number, in addition to those presented in the original work, is appended.

ESTIMATION OF THE CRITICAL VISCOUS SUB-LAYER IN SHOCK WAVE BOUNDARY LAYER INTERACTION. A. K. Roy. ZAMP, Jan. 25, 1959, pp. 82-89. Determination of the critical sublayer thickness, using experimental data obtained by Liepmann, Roshko, and Dhawan. Results indicate that, when expressed in terms of the undisturbed boundary thickness, the ratio of the critical viscous sublayer to the total boundary-layer thickness is approximately 1/10 in the laminar case and 1/100 in the turbulent case. These results support Lighthill's conjecture that the critical viscous sublayer is very small and well inside the so-called laminar sublayer in the turbulent case.

THE STEADY COMPRESSIBLE LAMINAR BOUNDARY LAYER, WITH ARBITRARY PRESSURE GRADIENT AND UNIFORM WALL TEMPERATURE. N. Curle. Royal Soc. (London) Proc., Ser. A, Jan. 1, 1959, pp. 206-224. 17 refs. Presentation of a simplified method for dealing with the effects of heat transfer from a uniform temperature wall. An approximate integral is derived from the energy equation by expressing the total temperature as a quadratic function of velocity, the Prandtl Number being taken as unity. The three coefficients are chosen to satisfy the two temperature boundary conditions and to give the correct temperature profile in the outer part of the boundary layer. Comparison with exact theory indicates that an error in the predicted separation position increases with Mach Number and is about 20% and 40% at Mach Numbers of 3 and 4, respectively. A detailed distribution of skin friction gives similar accuracy. A tentative empirical correction reduces the error to about 10% at a Mach Number of 4.

FLUCTUATION MEASUREMENTS IN SUPERSONIC TURBULENT BOUNDARY LAYERS. A. L. Kistler. US, BRL Rep. 1052, Aug., 1958. 53 pp. 10 refs. Presentation of measurements of the fluctuation in a boundary layer without pressure gradient or heat transfer for Mach Numbers up to 4.67. Results show that the distribution of the static temperature fluctuation levels through the boundary layer is similar at the various Mach Numbers and the levels are proportional to the mean static temperature difference across the boundary layer. The velocity fluctuation levels decrease slightly with increasing Mach Number. A high negative correlation exists between the velocity and temperature fluctuation at all Mach Numbers.

EXPERIMENTAL INVESTIGATION OF THE PRESSURE RISE REQUIRED FOR THE INCIPIENT SEPARATION OF TURBULENT BOUNDARY LAYERS IN TWO-DIMENSIONAL SUPERSONIC FLOW. D. M. Kuehn. US, NASA Memo. 1-21-59A, Feb., 1959. 48 pp. Study made on two-dimensional compression corners, curved surfaces, and incident-shock models. The tests were conducted over a range of Reynolds Numbers, based upon boundary-layer thickness, from 1.5×10^4 to 7.5×10^4 and Mach Numbers from 1.6 to 4.2. Results show that Mach Number, Reynolds Number, and model shape are important variables affecting the pressure-rise ratio for incipient separation. Observations are also made of the degree of unsteadiness associated with various separated flows when the conditions for incipient separation have been exceeded.

Control Surfaces

LOW REYNOLDS NUMBER AERODYNAMICS OF FLAPPED AIRFOILS AT SUPERSONIC SPEEDS. J. L. Amick and G. F. Carvalho. USAF WADC TR 58-466 [AD 155854], Sept., 1958. 85 pp. 21 refs. Theoretical and experimental investigation of plain and flapped airfoils at Reynolds Numbers sufficiently low to preclude transition in separated mixing layers. The theoretical results are based on a semiempirical equation for the pressure rise at laminar separation. Experimental results are in general agreement with theoretical predictions of lift when laminar separation is taken into account. The lift due to flap deflection at zero angle of attack is about half that obtained at Reynolds Numbers high enough to give turbulent flow.

Flow of Fluids

SOME NONLINEAR EFFECT IN COMPRESSIBLE FLOW. Haruo Moriguchi. Phys. Soc. Japan J., Dec., 1958, pp. 1, 510-1, 516. Application of the Imai method to study the two-dimensional potential flow of a compressible fluid past a family of cylindrical profiles with two parameters including an elliptic cylinder and a Kaplan bump. The effect of free-stream Mach Number on the curvature variation of the velocity distribution is analyzed, and a comparison with the case of Cherry's profile is made. An example shows that the surface velocity distribution changes its character with increasing Mach Number.

A LINEARIZED METHOD OF CHARACTERISTICS FOR DETERMINING BODY AERODYNAMIC FORCES AT ANGLE OF ATTACK. Appendix A - DETERMINATION OF w_2. Appendix B - CONDITION BEHIND SHOCK. Appendix C - REAL GAS SPEED OF SOUND EXPRESSION. Appendix D - ROTATION OF FLOW. Appendix E - RELATION

BETWEEN a AND a_1. J. J. Der. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 109-138. Modification of the axially symmetric method of characteristics for the determination of the flow field around bodies of revolution at small angles of attack. The first-order perturbation velocity which is introduced yields a simple perturbation equation of motion. The perturbation equation, in turn, is transformed into a finite difference equation readily integrable along known characteristic lines. Real gas effects are taken into account in determining the flow properties.

AN EXTENSION OF SECOND-ORDER SHOCK EXPANSION THEORY. R. Capiaux. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 63-99. Presentation of a second-order shock expansion method to determine the pressure distribution on bodies of revolution at angles of attack equal or close to zero. Normal force and moment derivative expressions for angles of attack approaching zero are also derived, and approximate expressions for blunt nosed bodies are presented. Findings from experimental data and results from other methods of solution are used for simplification purposes.

INVESTIGATION OF SPHERICAL-WAVE-INITIATED FLOW FIELDS AROUND BODIES. Appendix - COMPUTATION OF BLAST FLUID FLOW. D. R. McFarland. US, NASA Memo. 1-6-59L, Feb., 1959. 48 pp. 12 refs. Application of a bullet-optical technique to obtain measurements of the velocity fields and vortex movements about various blunt-shaped bodies undergoing a spherical blast wave with a peak positive overpressure of 4 psi. The velocity flow fields are shown at various flow times following passage of the blast front for different models. Vortex movements with time are compared for square-bar models of various aspect ratios. Schlieren photographs indicate that the leading-edge vortex dissipates faster than the trailing-edge vortex. Results show that corner sharpness has no discernible effect on the overall disturbed velocity fields or vortex movements for the square-bar models used.

INCOMPRESSIBLE VISCOUS FLOWS PAST PARABOLOIDS. R. M. Mark. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 1-7. Derivation of an analytical solution of the Navier-Stokes equations for incompressible viscous flow in the region far downstream of the nose of paraboloids. The solution is uniformly valid across the whole viscous layer for the complete range of Reynolds Numbers based on the focal length.

MEASUREMENT OF TWO-POINT CORRELATIONS OF THE SURFACE PRESSURE ON A CIRCULAR CYLINDER. V. Prendergast. UTIA TN 23 (AFOSR TN 58-861) [AD 203674], July, 1958. 28 pp. Test results from two-point correlations of the surface pressure on a cylinder mounted at right angles to the flow. The curves of correlation coefficient versus hole spacing did not follow the expected form, in that the correlation curves approached a constant value rather than zero, as the hole spacing was increased to very large values. Three possible explanations are offered but none is completely satisfactory. A correction involving a simple scale expansion has been employed to alter the form of the curves so that they approach zero at large hole spacings, which appears to give at least a good first approximation to the ideal free-field, rigid-cylinder correlation.

SLENDER BODY OF REVOLUTION AT HYPERSONIC SPEEDS - AN APPROXIMATION TO THE DETERMINATION OF THE FLOW FIELD. R. Capiaux. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 101-108. Derivation of a simple method to determine the flow field around bodies of revolution flying at hypersonic speeds and zero angle of attack. The small disturbance equation of motion is examined, and a simple solution in the plane transverse to the body axis is found. The solution predicts the flow field around the body as well as the position of the shock wave. A similarity parameter is introduced whereby the flow field depends uniquely on the value of the local hypersonic similarity parameter.

SUPERSONIC FLOW AROUND BLUNT BODIES - AN EXTENSION OF VAN DYKE'S TECHNIQUE. Appendix - INITIAL CONDITIONS FOR THE BLUNT BODY PROBLEM. M. Vinokur and R. W. Sanders. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 41-56. Extension of Van Dyke's numerical method for the supersonic blunt-body problem to include real gas effects and to broaden the class of bodies generated. Several changes in the procedure followed by Van Dyke are made to obtain more accurate results. A sample flow calculation is presented. Results are discussed and a graphical representation is made of the body and sonic line resulting from a hyperbolic shock for M = 6.0 and of the pressure distribution over the same body as a function of the body angle.

INVISCID HYPERSONIC FLOW AROUND BLUNT BODIES. M. Vinokur. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 1-39. 21 refs. Analysis of the inviscid supersonic blunt body problem. The difficulties in getting accurate analytic solutions are discussed. The equations for the general problem are formulated and a method for finding the constant density solution for arbitrary bodies is indicated. The case of an oblate ellipsoid of revolution is worked out in detail for illustration purposes. The solution reduces to that of Lighthill for a sphere. Results are discussed and compared with those of other theories and with available experimental data.

HYPERSONIC FLOW NEAR THE FORWARD STAGNATION POINT OF A BLUNT-NOSED BODY OF REVOLUTION. Hakuro Oguchi. Tokyo U. Aero. Res. Inst. Rep. 337, Nov., 1958. 209 pp. 12 refs. Presentation of a theoretical method that takes into account the effect of viscosity and makes the simplifying assumptions that the flow is incompressible downstream of the shock wave, and

the radial distance r is nearly equal to the distance x measured along the surface from the stagnation point. The method yields the solution of the Navier-Stokes equations; however, the solution can only be evaluated by numerical integration. An alternative method is presented, yielding an analytical expression of the solution, applicable only to the case of large Reynolds Numbers. Results obtained by both methods show good agreement. It is concluded that there exists a similar solution consistent with the conditions both at the shock wave and on the body surface. The surface pressure coefficient obeys the modified Newtonian law independently of the viscosity effect.

SURFACE PRESSURE DISTRIBUTION ON BLUNT BODIES AT SUPERSONIC SPEEDS. R. M. Mark. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 57-62. Analytical determination of the pressure distribution in the stagnation-point region of blunt bodies using the governing inviscid flow equations. The effect of the compressibility of the fluid in the rotational flow region between the curved, detached shock wave and the body is studied. Some symplifying approximations are made, and the results are found to be in good agreement with experimental data.

AN EXPERIMENTAL INVESTIGATION OF BLUNT BODY STAGNATION POINT VELOCITY GRADIENT. J. C. Boison and H. A. Curtiss. ARS J., Feb., 1959, pp. 130-135. 14 refs. Test results on five axisymmetric spherical-segment shapes ranging in bluntness from concave to the equivalent of hemispherical. Experiments covered Mach Numbers of 2.01, 3.01, and 4.76 and Reynolds Numbers based on body diameter from 1 to 1.5 million. Pressure distributions were obtained to a high degree of accuracy by micromanometer techniques and by the use of numerous pressure orifices. A correlation of stagnation point velocity gradient with a bluntness parameter based on the sonic point coordinates is obtained. Modified Newtonian theory is found to be reasonably accurate for predicting the stagnation velocity gradient of near-hemispherical shapes, but current theories for a truncated cylinder predicted values considerably greater than the experimental results. As a by-product, two shock detachment correlations are obtained, one using an effective nose radius parameter to compare bodies of varying bluntness with shock density ratio, and the other using a bluntness parameter to obtain an almost linear variation of shock detachment distance and shock sonic point location.

THEORY OF THIN AIRFOILS IN FLUIDS OF HIGH ELECTRICAL CONDUCTIVITY. W. R. Sears and E. L. Resler, Jr. Cornell U. Grad. Sch. Aero. Eng. Rep. (AFOSR TN 58-973) [AD 205599], Aug., 1958. 38 pp. Study of the steady flow of an incompressible fluid past thin cylindrical bodies with parallel and perpendicular orientation of the magnetic field to the uniform stream. In the first case, the flow of an infinitely conducting fluid is shown to be irrotational and current-free except for surface currents at the walls of the obstacles. With large but finite conductivity the surface currents are replaced by thin boundary layers of large current density. In the second case, for infinite conductivity the flow field is made up of an irrotational current-free part and a system of waves involving currents and vorticity extending out from the body. For large, finite conductivity these waves attenuate exponentially with distance from the body. The forces on sinusoidal walls are calculated for both cases.

MAGNETOHYDRODYNAMIC FLOW IN A SHOCK TUBE. M. Mitchner. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 1-34. (Also in Phys. Fluids, Jan.-Feb., 1959, pp. 62-71.) Analysis of the effect of a transverse magnetic field on the motion of a perfectly conducting fluid in a shock tube. A generalized form of the Riemann invariant for the continuous motion of such a fluid is combined with the conservation equations for a magnetohydrodynamic shock to obtain an exact description of the fluid motion in a shock tube in terms of arbitrary initial conditions. The fluids are assumed to have constant specific heat ratios. Qualitatively, the effect of the magnetic field is equivalent to that of pressure, but quantitatively the effect is always greater than merely the hydrodynamic pressure equivalent to the appropriate Maxwell stress. A magnetic field in the high-pressure region alone can produce shocks having Mach Numbers for typical laboratory conditions of the order of hundred or more, and is in general agreement with available experimental results.

EFFECT OF TRANSVERSE MAGNETIC FIELD ON THE FLOW DUE TO AN OSCILLATING FLAT PLATE. Tsunehiko Kakutani. Phys. Soc. Japan J., Dec., 1958, pp. 1, 504-1, 509. Determination of the velocity distributions, magnetic field, and related quantities (such as pressure, electric field and current density) for the flow of an incompressible, viscous, and electrically conducting fluid due to an infinite oscillating flat plate in the presence of a transverse magnetic field. General solutions are derived, and some special cases corresponding to limiting values of various parameters are discussed. It is shown that each of the velocity distributions and other related quantities consists of two different oscillations whose decaying factors differ from the corresponding wave numbers.

SUPERSONIC TWO-DIMENSIONAL MAGNETOHYDRODYNAMIC FLOW. Appendix - DETERMINATION OF THE "FREE STREAM" CONDITIONS IN THE SHOCK TUBE. F. Fishman, J. W. Lothrop, R. M. Patrick, and H. E. Petschek. Avco Res. Lab. RR 39, Feb., 1959. 49 pp. USAF-supported application of a perturbation theory to the supersonic flow of a conducting fluid through the magnetic field of a circular solenoid. These calculations describe the lift and drag forces on the solenoid as well as the gas conditions everywhere in the flow field within the limit of weak interaction between the magnetic field and the flow. Calibrated view camera pictures of the light emitted by the gas are in

agreement with predictions based on perturbation theory. Experimental verification is given of the prediction that lift forces can be achieved with geometrically symmetric bodies by utilizing the Hall effect. Estimates of the experimental lift forces indicate a lift coefficient of about 0.4 and a lift-drag ratio of approximately unity.

ON THE CONFINEMENT OF A PLASMA BY MAGNETOSTATIC FIELDS. E. S. Weibel. Phys. Fluids, Jan.-Feb., 1959, pp. 52-56. 10 refs. Study of a plasma treated as an assembly of classical particles having masses m_+ and m_- and charges $\pm e$. It is shown that if such a plasma is in thermodynamic equilibrium it is unaffected by a magnetostatic field. In particular, it cannot be confined by a magnetostatic field and at the same time be in equilibrium. In absence of collisions there exist stationary solutions for the magnetic field and the particle distribution in phase space such that the gas is confined. The solutions are self-consistent, meaning that the particle motions generate the field, which in turn maintains the particle distribution. However, this distribution may not be Maxwellian. As an example the linear pinch is treated. The fields, the particle number densities, and the current density are calculated for a particular case.

THEORETICAL STRUCTURE OF PLASMA EQUATIONS. M. N. Rosenbluth and N. Rostoker. Phys. Fluids, Jan.-Feb., 1959, pp. 23-30. 10 refs. Development of a new method for the solution of the linearized transport equation. By facilitating direct use of the properties of particle orbits, a considerable simplification is achieved. In particular, a variational expression is derived for determining stability which is rogorous in the limit of small Larmor radius.

PLASMA ACCELERATION BY MEANS OF A ROTATING MAGNETIC FIELD. V. Vali and J. Gauger. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 35-41. Development of a technique for accelerating hydrogen plasmas to velocities of the order of 1% of the velocity of light. At this velocity, the kinetic energy per particle of a deuterium plasma is approximately 10^5ev. The system would utilize an electrodeless discharge so that no high atomic number contaminants are introduced, other than those boiled off the gas container walls. The apparatus would consist of a cylindrical glass tube with four radio-frequency oscillator coils placed around it to produce a rotating magnetic field.

THE VIBRATIONAL RELAXATION OF NITRIC OXIDE. F. Robben. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 65-83. 12 refs. Experimental investigation using a spectrophotometric technique covering a temperature range from 450°K. to 1,300°K. and relaxation times on the order of 5 to 10 microsec. Computations of the probability of de-excitation from the first vibrational level - made according to the theory of Schwartz, Slawsky, and Herzfeld with an interaction potential derived from viscosity measurements - are on the order of 2×10^{-5} less than the experimental values. Use of a potential derived from an $(NO)_2$ complex appears to account for the discrepancy.

KINETICS OF DISSOCIATION OF NITRIC OXIDE. D. M. Mason. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 43-49. Analysis of the kinetics of the dissociation of nitric oxide with particular regard to reaction rates and the mechanism of the reaction as presented by previous investigators. Rate constants obtained from the extrapolation of experimental values at 2,000°K. are used to compute relationships between concentration and time for nitric oxide at temperatures of 3,000°K. and 5,000°K.

EQUILIBRIUM COMPOSITION AND THERMODYNAMIC PROPERTIES OF A 50-50 NITROGEN-OXYGEN MIXTURE. F. Robben. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 51-64. Presentation of the results for the solution of the equilibrium equations of molecular and atomic nitrogen and oxygen, along with nitric oxide. Mole fractions, enthalpy, and partition functions of the various components, in addition to mean molecular weight, density, and enthalpy of the entire fluid, are presented as a function of temperatures within the range of 1,000° K. to 5,000°K.

STAGNATION POINT HEAT TRANSFER IN PARTIALLY-IONIZED ARGON. R. W. Rutowski. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 179-205. 10 refs. Analytical and experimental investigation of the influence of ionization in stagnation point heat transfer. Shock-tube measurements made on a model in argon are evaluated, and the results are compared with values predicted by using computed stagnation-point properties under the assumption of equilibrium flow. Very good agreement is obtained for flows in which the argon is not yet ionized. This discrepancy is evidently due to the effect of ionization on the transport properties.

THE NEWTONIAN-DIFFUSE METHOD FOR COMPUTING AERODYNAMIC FORCES. Appendix - MOMENT ACCORDING TO FREE-MOLECULAR THEORY. W. A. Gustafson. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. II, Jan., 1959, pp. 139-163. Analysis of the aerodynamic characteristics of basic shapes in rarefied flows. The analyses are based on the assumption of Newtonian flow with diffuse-particle reflection. Expressions are obtained for computing the aerodynamic moment and the drag forces on spherical segments, conical frustums, and cylinders for arbitrary angles of attack. The moment on a cylinder is also derived in accordance with the free molecular theory.

THEORETICAL STUDIES OF UNSTEADY TRANSONIC FLOW. II - THE OSCILLATING SEMI-INFINITE RECTANGULAR WING. M. T. Landahl. Sweden, Flygtekniska Försöksanstalten, FFA Medd.

78, July, 1958. 20 pp. Calculation of the aerodynamic forces on a wing in transonic flow by use of Fourier transforms. The results show that three-dimensional side-edge effects are very important and will modify the ordinary two-dimensional strip-theory values considerably, including sections that are fairly well removed from the side edges. The results may be used also to obtain approximate air forces on a finite rectangular wing for low values of $A\sqrt{k}$, where A is aspect ratio and k the reduced frequency. Then the mutual side-edge interference may be neglected and the effect from each side edge calculated separately.

THEORETICAL STUDIES OF UNSTEADY TRANSONIC FLOW. III - THE OSCILLATING LOW ASPECT RATIO RECTANGULAR WING. M. T. Landahl. Sweden, Flygtekniska Försöksanstalten, FFA Medd. 79, Aug., 1958. 15 pp. Calculation of the aerodynamic forces on a low aspect ratio wing by expanding the velocity potential in an asymptotic series. The approximate theory is valid for small values of $k\sigma^2$ (σ = semispan-to-chord ratio; k = reduced frequency) and complements an earlier theory valid only for pointed wings. Formulas are given for the calculation of generalized forces for any smooth, flexible, or rigid mode of oscillation with spanwise symmetry. Comparison with steady-wing theory shows that the unsteady-flow effects are appreciable even at fairly low reduced frequencies.

NON-SIMILARITY THEORY OF DECAYING TURBULENCE. Yutaka Shigemitsu. Phys. Soc. Japan J., Jan., 1959, pp. 91-103. 18 refs. Extension of the initial-period similarity law of decaying turbulence in order to include nonsimilarity characteristics. Based upon the cascade concept that large vortices produce small ones successively, a Poisson process for the mixture of these vortices is introduced, and nonstationary expressions of Reynolds stress and Euler correlation are derived. By evaluating the expressions in an approximate manner a decay law is obtained that deviates gradually from the linear decay law.

ON THE VISCOUS CORE OF A LINE VORTEX. II. Nicholas Rott. ZAMP, Jan. 25, 1959, pp. 73-81. Calculation of the temperature distribution in the viscous core of a vortex flow aligned with an axisymmetric stagnation-point inflow. For the limiting case of small viscosity and compressibility, closed solutions for various Prandtl Numbers are presented. A noticeable cooling effect is observed in the vortex core, thus showing that recovery rules from the boundary-layer theory cannot be applied to the viscous core of a vortex.

SHOCK-GENERATED VORTICITY EFFECTS AT LOW REYNOLDS NUMBERS. H. Hoshizaki. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. I, Jan., 1959, pp. 9-43. 10 refs. Investigation of vorticity effects on stagnation-point heat transfer rates of a hemisphere. The complete Navier-Stokes equations are considered in the flow region between the bow shock and the body. Boundary conditions are applied immediately behind the shock and at the wall. By specifying the form of the stream function, the Navier-Stokes equations are reduced to a total differential equation. Solutions to the total differential equation are then obtained by successive numerical approximations. The numerical results indicate that shock-generated vorticity substantially increases heat transfer rates over boundary-layer values for Reynolds Numbers below 10^4. Furthermore, it is shown that, for Prandtl Number equaling one, the increase in heat transfer is approximately inversely proportional to the difference between the vorticity at the wall and the vorticity immediately behind the shock.

Internal Flow

PRESSURE DISTRIBUTION MEASUREMENTS ON TWO-DIMENSIONAL CASCADES AT HIGH SUBSONIC MACH NUMBERS. I. K. H. Grewe. DFL Inst. Aero. Bericht No. 70, Mar. 12, 1957. 47 pp. Presentation of wind-tunnel measurements of the pressure distribution on cascades in compressible flow at high subsonic Mach Numbers. Two-dimensional cascades with systematically varying solidity ratio, blade angle, and angle of inflow were used for the investigation. Results indicate that the pressure distribution over the blade surface can be determined mainly by the nonviscous flow, as long as the critical Mach Number is not reached. A comparison of experimental data with theoretical results of the Prandtl-Glauert rule shows good agreement.

ZUSAMMENHANG DER STRÖMUNGSEIGENSCHAFTEN DES LAUFRADES EINES AXIALGEBLÄSES MIT DENEN EINES EINZELFLÜGELS. Günther Muesmann. ZFW, Dec., 1958, pp. 345-358. In German. Theoretical and experimental investigation of the applicability of measurements obtained on single airfoils to rotating turbine blades. The flow pattern observed in both cases is compared. Wind-tunnel experiments on single airfoils and axial-compressor rotors cover the Reynolds Number range of 10,000 and 400,000; pressure increase and rotor efficiency are determined by means of the aerodynamic coefficients derived for the two-dimensional flow; and three-dimensional wake surveys and boundary layer observations are also included.

A GREEN'S FUNCTION SOLUTION FOR THE CASE OF LAMINAR INCOMPRESSIBLE FLOW BETWEEN NON-CONCENTRIC CIRCULAR CYLINDERS. J. F. Heyda. Franklin Inst. J., Jan., 1959, pp. 25-34. Derivation of Green's function in bipolar coordinates for the potential equation for a nonconcentric annular region. The function is then used to solve Poisson's equation for the point velocity in laminar incompressible flow between nonconcentric circular cylinders. When the eccentricity of the annular region tends to zero, this velocity formulation reduces to the well-known result for a concentric annulus.

FLOW OF A COMPRESSIBLE FLUID IN A HYPERBOLIC CHANNEL. Hasan Özoklav. J. Math. & Mech., Jan., 1959, pp. 27-45. 14 refs.

Presentation of the compatibility equations of gases showing that it is possible to eliminate the pressure and the density between the equations satisfied by the motion, and thus obtain a certain number of relations which contain only the velocity field V and the external force F. The compatibility equations are then applied to the problem of flow in a hyperbolic channel, making use of the Riemann method of integration. Numerical calculations are made for the velocity at the narrow section and intermediate section of the channel, as well as for the pressure along the wall.

SUCTION AND POWER REQUIREMENTS OF A VENTILATED WALL "HALF-NOZZLE" AT TRANSONIC SPEEDS. D. M. Rao and S. M. Ramachandra. Aero. Soc. India J., Nov., 1958, pp. 63-69. Investigation of a slotted wall and a perforated wall fitted in a two-dimensional half-nozzle configuration and employing a plenum suction. Results indicate suction flow requirements considerably in excess of the quantities needed by normal ventilated nozzles in the Mach Number range 0.8 - 1.05. Measurements of diffuser power show substantial benefits of employing suction with a half-nozzle. Effects of nozzle length/height ratio and divergence angle on suction and power are demonstrated, and it is shown that an optimum combination of divergence and suction can yield useful tunnel power reductions in the entire transonic range.

ESTIMATED PERFORMANCE OF RADIAL-FLOW EXIT NOZZLES FOR AIR IN CHEMICAL EQUILIBRIUM. Appendix A - DERIVATION OF AVERAGE COSINE OF ANGLE BETWEEN POTENTIAL-FLOW VELOCITY VECTORS AND NOZZLE AXIS. Appendix B - DETERMINATION OF PROFILE PARAMETER. G. W. Englert and F. D. Kochendorfer. US, NASA Memo. 1-5-59E, Feb., 1959. 53 pp. 11 refs. Presentation of computation for thrust, boundary-layer, and heat-transfer characteristics of nozzles having radial flow in the divergent part. Stagnation pressure varied from one to 32 atmospheres, stagnation temperature from 1,000° to 6,000°R., and wall temperature from 1,000° to 3,000°R. Design pressure ratio was varied from 5 to 320 and operating pressure ratio from 0.25 to eight times the design pressure ratio. Results are generalized independently of divergence angle and of stagnation pressure in the temperature range of 1,000° to 3,000°R. A means of determining the aerodynamically optimum wall angle is provided.

INDUCED AIR FLOWS IN FUEL SPRAYS. Hikmet Binark and W. E. Ranz. Penn. State U., Squid TR PSU-1-P [AD 156507], Apr., 1958. 25 pp. Measurement of the magnitude of the air velocities both outside and inside a hollow cone spray. The velocity outside the spray decreased with increased distance from the orifice and increased distance from the spray sheet. Velocities inside the spray cone were higher than the corresponding velocities outside the spray cone and decreased with increased distance from the nozzle orifice. The air velocity increased with increased liquid supply pressure. Considering a unit area of the spray sheet, continuity required that the velocity of air leaving the sheet be equal to the velocity entering the sheet divided by the sine of half the spray cone angle.

Jet Flaps & Wings

THE GROUND EFFECT ON THE JET FLAP IN TWO DIMENSIONS. D. J. Huggett. Aero. Quart., Feb., 1959, pp. 28-46. 10 refs. Investigation of the ground effect for jet-flap airfoils with reference to the conditions under which the jet flow hits the ground. Experimental results are included for the change of lift and pitching moment for 58.1° and 31.4° jet-deflection angles, with a limited investigation into the downwash changes behind the model with a 58.1° jet-deflection angle. It is concluded that there is a definite limit to the jet coefficient which may be used at any ground position, if the problems of a sudden change of lift and pitching moment are to be avoided. A provisional assessment of the performance of a jet-flap aircraft near the ground is made, showing that for a 58.1° jet-deflection angle there is a definite limit to the minimum flying speed for any given distance of the wing from the ground.

LOW-SPEED WIND-TUNNEL INVESTIGATION TO DETERMINE THE AERODYNAMIC CHARACTERISTICS OF A RECTANGULAR WING EQUIPPED WITH A FULL-SPAN AND AN INBOARD HALF-SPAN JET-AUGMENTED FLAP DEFLECTED 55°. T. G. Gainer. US, NASA Memo. 1-27-59L, Feb., 1959. 21 pp. Experimental investigation to obtain a comparison of the aerodynamic characteristics of full-span and half-span jet-augmented flaps. Results indicate that the ratio of total lift to jet-reaction lift for the wing is about 35% less for the half-span than for the full-span jet-augmented flap. The reduction of the span of the jet-augmented flap from full to half span reduces the maximum value of jet-circulation lift coefficient from about 6.8 to 2.2. The half-span jet-augmented flap gives thrust recoveries considerably poorer than those obtained with the full-span flaps.

FULL-SCALE WIND-TUNNEL INVESTIGATION OF A JET FLAP IN CONJUNCTION WITH A PLAIN FLAP WITH BLOWING BOUNDARY-LAYER CONTROL ON A 35° SWEPTBACK-WING AIRPLANE. Appendix - THEORETICAL COMPUTATION OF JET FLAP EFFECTIVENESS. Kiyoshi Aoyagi and D. H. Hickey. US, NASA Memo. 2-20-59A, Mar., 1959. 25 pp. Study to determine whether blowing simultaneously at the hinge-line radius and trailing edge would be more effective than blowing separately at either location. Of the three flap blowing arrangements tested, blowing distributed between the trailing edge and the hinge-line radius of a plain flap was found to be superior to blowing at either location separately. Comparison of estimated and experimental jet flap effectiveness was fair to good depending upon the momentum coefficient.

Performance

CARATTERISTICHE DI VOLO E REGIMI PARTICOLARI DEGLI AEROMOBILI A SOSTENTA-

ZIONE MISTA. G. B. Nicolò. L'Aerotecnica, Oct., 1958, pp. 269-284. 13 refs. In Italian. Analysis made to determine the best coordination between thrust angle and angle of attack in order to achieve minimum thrust, maximum range, maximum and minimum speed, and maximum angle of climb. Consideration is given to the existence of four different possible conditions of flight with the same lift-drag ratio, thrust, and slope. A study is made of the optimum relation between thrust angle and angle of attack during take off. It is concluded that the best thrust angle in each case is a function of the angle of attack as in conventional aircraft.

Wings & Airfoils

A NUMERICAL METHOD OF EVALUATING THE VELOCITY POTENTIAL AND THE MINIMUM DRAG WARPING OF ARBITRARY SUPERSONIC WINGS. Max Anliker. ZAMP, Jan. 25, 1959, pp. 1-15. 18 refs. Calculation of the drag due to lift from velocity potential influence coefficients and evaluation of minimum drag warping. Results obtained by means of the numerical method show good agreement with the corresponding analytical and semianalytical values in the case of delta and pointed tip wings. The advantages of the method and its applicability to the optimum drag problem are discussed.

SUPERSONIC FLOW PAST SLENDER POINTED WINGS WITH "SIMILAR" CROSS SECTIONS AT ZERO LIFT. W. T. Lord and G. G. Brebner. Aero. Quart., Feb., 1959, pp. 79-102. 14 refs. Extension of some recent theoretical work on slender pointed wings in order to find wings with simple geometry, low wave drag, and pressure distributions which are unlikely to be seriously affected by viscous effects. Wave drag and pressure distributions are calculated by slender-wing theory. General formulas are given for the wave drag and the overall pressure distribution, with particular emphasis on the root pressure distribution. Results for a number of wings of special interest are presented and discussed.

AN IMPROVEMENT OF THE VELOCITY DISTRIBUTION PREDICTED BY LINEAR THEORY FOR WINGS WITH STRAIGHT SUBSONIC LEADING EDGES. D. G. Randall. Gt. Brit., RAE TN Aero. 2577, Sept., 1958. 21 pp. Analysis of the problem of calculating supersonic flow over the subsonic edges of a nonlifting wing. When calculated by thin wing theory, the results are unacceptable in a small region near the leading edge. By satisfying the boundary condition more exactly near the leading edge of the wing, a solution of the linearized equation is obtained which gives plausible results. This treatment is inconsistent (except for slender wings) because it retains second order terms in the boundary condition, but drops them in the differential equations. The flow quantities obtained by means of this method behave correctly near the leading edge, while they do not significantly differ from the linear-theory values over most of the wing.

SUBSONIC WING LOADINGS ON A 45° SWEPTBACK-WING AND BODY COMBINATION AT HIGH ANGLES OF ATTACK. Appendix A - EXACT RELATIONS FOR VELOCITY AND ANGLE-OF-ATTACK COMPONENTS. Appendix B - CHARACTERISTICS OF THE SINGLE PANEL. J. A. Axelson and J. F. Haacker. US, NASA Memo. 1-18-59A, Feb., 1959. 57 pp. 13 refs. Investigation of the subsonic pressure distributions and loadings for a wing-body combination at angles of attack up to 36°. The wing has an aspect ratio of 5.5 and a taper ratio of 0.53; test results are presented for Mach Numbers from 0.30 and 0.50. A degree of correlation is found between the stall patterns and spanwise load distributions for the present model and for three other 45° sweptback-wing and body combinations having wings of aspect ratios from 4.0 to 8.0. The correlation was considered useful for extrapolating the Weissinger span-loading method to higher angles of attack for wings similar to those included in the correlation. A tentative approach has been introduced wherein the normal forces on a sweptback wing can be distributed across the span for angles of attack above 20°.

TWO-DIMENSIONAL, SUPERSONIC, LINEARIZED FLOW WITH HEAT ADDITION. Harvard Lomax. US, NASA Memo. 1-10-59A, Feb., 1959. 35 pp. Presentation of calculations for the forces on a thin supersonic wing underneath which the air is heated. The analysis is limited principally to linearized theory, but some nonlinear effects are also considered. The validity of linearized equations and their solutions in two and three dimensions are discussed. A simple expression is derived for the lift and drag on arbitrary, planar, two-dimensional wings in fields with arbitrary heat addition. Optimum wings in heated supersonic fields, as well as the effect of combining engine thrust with the lift and thrust provided by external heating are also considered. A particular example is presented to evaluate the results, and remarks on nonlinear effects are made. It is shown that significant advantages to external heating exist if the heat is added well below and ahead of the wing.

SOLUTIONS OF SUPERSONIC INTERFERENCE PROBLEMS BY GENERALIZED INTEGRAL RELATIONSHIP - EXAMPLES FOR A CIRCULAR CYLINDRICAL BODY. Lu Ting. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 465 (AFOSR TN 58-1069) [AD 207229], Oct., 1958. 43 pp. Development of a procedure that represents the pressure distribution on the body and the wing inside the interference region by a linear combination of a finite number of elementary functions of the surface variables. The combination fulfills the condition that the pressure is continuous inside the interference region and also across its boundary. The arbitrary constants in the combination are determined by a generalized integral relationship which is reduced to a set of simultaneous linear algebraic equations. A numerical example is carried out for a circular cylindrical body mounted on a semi-infinite plate. The results are in agreement with those obtained

by Nielsen by means of a different theoretical method.

AEROELASTICITY

APPLICATION OF THE METHOD OF STEIN AND SANDERS TO THE CALCULATION OF VIBRATION CHARACTERISTICS OF A 45° DELTA-WING SPECIMEN. J. M. Hedgepeth and P. G. Waner, Jr. US, NASA Memo. 2-1-59L, Feb., 1959. 26 pp. Calculation of generalized influence coefficients by the method of Stein and Sanders for a built-up delta wing specimen. These are used together with appropriate generalized masses to obtain the natural modes and frequencies in symmetric and antisymmetric free-free vibration. The resulting frequencies are compared with those obtained experimentally and found to be consistently high. Possible sources of the disparities are discussed.

EVALUATION OF THE LEVY METHOD AS APPLIED TO VIBRATIONS OF A 45° DELTA WING. Appendix - FREEING OF INFLUENCE-COEFFICIENT MATRIX FOR GENERAL THREE-POINT SUPPORT. E. T. Kruszewski and P. G. Waner, Jr. US, NASA Memo. 2-2-59L, Feb., 1959. 48 pp. 10 refs. Application of the Levy method to obtain the natural modes and frequencies of a large-scale built-up delta wing. Results, both with and without the effects of transverse shear, are compared with experimental results and with those of the Stein-Sanders method. The comparison shows that Levy's method gives good results for thin-skin delta wings, provided that corrections are made for the effect of transverse shear.

WIND TUNNEL TESTS ON THE EFFECTS OF AN ADDED MASS ON THE FLUTTER OF A MODEL DELTA WING. I - FIXED ROOT FLUTTER TESTS. II - ANTI-SYMMETRIC FLUTTER TESTS. III - SYMMETRIC FLUTTER TESTS. H. Hall and W. A. Coles. Gt. Brit., RAE Rep. Struc. 240, Sept., 1958. 51 pp. Investigation of antisymmetric and symmetric flutter characteristics in which the parameters that are varied include the mass value, the spanwise and chordwise position of the mass, and the mass pitching radius of gyration. In the body freedom tests the fuselage inertia characteristics are also varied. Five different types of flutter are obtained, depending on these parameters and the particular root condition. The test results indicate that either symmetric or antisymmetric flutter may be critical, depending on mass value and c.g. position and that the optimum position of the added mass is in the neighborhood of 0.75 span and well forward in the chord.

VIBRATION OF BEAMS - A RECURRENCE APPROACH. Appendix A - SOME PROPERTIES OF GENERALISED STEP-FUNCTIONS. Appendix B - SCHEMATIC MULTIPLICATION OF POLYNOMIALS. P. M. Quinlan. Natl. U. Ireland, U. Coll., TN 6 (AFOSR TN 59-118) [AD 210423], Sept., 1958. 35 pp. Presentation of a new method for obtaining the vibration frequencies of a loaded beam. The frequency equation is obtained by the multiplication of two sets of polynomials, thus allowing the determination of the higher critical frequencies as readily as the lowest frequency. The method is developed in four stages by the aid of graded examples. Application is made to the torsional oscillations of a shaft under six masses.

DIFFERENTIAL EQUATION OF EQUILIBRIUM AND VIBRATION AND EXPRESSIONS FOR THE BOUNDARY CONDITIONS OF AN ORTHOTROPIC NON-HOMOGENEOUS PLATE. Zbigniew Mazurkiewicz. Arch. Mech. Stosowanej, No. 5, 1958, pp. 755-767. Derivation, in an orthogonal system of coordinates, of a differential equation and expressions for the boundary conditions of an orthotropic nonhomogeneous plate. Small deflections and an elastic nonhomogeneous foundation of the Winklerian type are assumed. The load is considered to be acting perpendicularly to the middle surface of the plate. The Hamiltonian principle is used as a basis for applying variational methods to a certain functional expression derived on the basis of the expressions for the potential and kinetic energy of the plate.

WYMUSZONE DRGANIA TŁUMIONE POWŁOKI OBROTOWEJ. Michał Lawina. Rozprawy Inżynierskie, No. 3, 1958, pp. 495-512. In Polish, with summaries in English and Russian. Analysis of the forced damped vibration of a shell of revolution of any form, the vibration-generating normal forces being of an arbitrary type. The Sorokin hypothesis is used in order to include the damping. The equations of amplitude distribution are integrated asymptotically and the vibration forcing action is represented as a superposition of partial actions. For the n-th order component of the vibration exciting force, the displacements are represented in a form containing separate intensity and variability functions. The integration of the amplitude distribution equations reduces to the solution of successive systems of equations, their solutions yielding successive approximations to the functions of displacement intensity. The first two approximations can be determined if the operators appearing as coefficients in the system of equations are known.

FUELS & LUBRICANTS

ANOMALOUS EXTINCTION PHENOMENA IN SOLID PROPELLANT BURNING. D. L. Reid, K. P. Hall, and Martin Summerfield. Princeton U., Squid TR PR-77-P [AD 156501], Apr., 1958. 19 pp. Study of ammonium chlorate (NH_4ClO_4) and potassium chlorate ($KClO_4$) propellants to determine flame extinction phenomena that occur within certain pressure limits when strands of propellant are burned in controlled atmospheres. For an uncatalyzed NH_4ClO_4 propellant, limits were observed at 400 and 1,300 psia for 1/8-in.-thick strands. For $KClO_4$, a pressure limit was observed such that steady burning was impossible at any pressure below 65 psia. The experiments indicated that the feedback from the gaseous flame zone controls the burning rate of a solid propellant.

INSTRUMENTS

Temperature Measuring Devices

STUDY OF THERMAL DISCONTINUITIES AND ASSOCIATED TEMPERATURE DISTURBANCES IN A SOLID SUBJECT TO A SURFACE HEAT FLUX. I - EFFECT OF THERMOCOUPLE CAVITY NEAR HEAT SINK SURFACE ON SINK TEMPERATURE DISTRIBUTION AND ITS MEASUREMENT. Appendix A - DERIVATION OF TEMPERATURE INCREASES DUE TO VOIDS USING POINT SOURCES. Appendix B, C - STEADY STATE ANALYTICAL SOLUTION FOR SEMI-INFINITE SLAB FOR LARGE RADIUS- VOID DEPTH RATIOS. J. V. Beck and H. Hurwicz. Avco Res. & Adv. Devel. Div. RAD TR-9-59-5, Feb. 20, 1959. 58 pp. 11 refs. Analysis of the surface temperature error in thermocouple measurement due to the presence of the thermocouple near the heated surface. The results are applicable to the flight conditions since the effects of time-variable heat fluxes and temperature-variable thermal properties are treated. The distance from the surface (null point) is determined where the thermocouple reads essentially the undisturbed surface temperature. Problem solutions are obtained with both analog and digital computing equipment, and results are compared with the work of previous investigators. In addition, two new analytical solutions are developed and shown to yield more exact results than those previously available.

MACHINE ELEMENTS

Rotating Discs & Shafts

A CREEP ANALYSIS OF ROTATING SOLID DISKS. B. M. Ma. Franklin Inst. J., Feb., 1959, pp. 149-165. 16 refs. Analysis of creep deformations and stress distributions in rotating solid discs operating at elevated temperature, based on the maximum shear theory. Several basic assumptions are made. The general equations for creep rates and deformations are presented. The case of the variable-thickness and uniform-temperature disc is discussed and analyzed for the steady-state condition. Test data indicate that, in general, for a given material the material creep number (n) depends mainly on stress and temperature, and the material creep modulus (σ_0) only slightly on temperature.

MISSILES, ROCKETS

ASUPRA REGIMULUI OPTIM DE FUNCŢIONARE A RACHETELOR. Lucian Dumitrescu. Stud. Cerc. Mec. Aplic., No. 2, 1958, pp. 285-296. In Rumanian, with summaries in English and Russian. Investigation of the optimum thrust programing of a space rocket. Discussion covers the motion of the rocket under the following assumptions: the air friction is neglected; the thrust acts radially, relative to the earth, and has constant magnitude during the combustion; the distance traveled during powered flight is small enough to allow the linearization of the terms of gravity variation in equations of motion. These equations are then solved by an iteration process which yields the speed and the distance traveled with power on, after which the motion of the rocket obeys the Kepler law. Two cases are studied: (a) a rocket taking off from an artificial satellite and (b) a multistage rocket launched vertically from the ground.

MATHEMATICAL THEORY OF THE OPTIMUM TRAJECTORIES OF A ROCKET. Angelo Miele. Purdue U. Sch. Aero. Eng. Final Rep. A-58-10 (AFOSR TR 58-154) [AD 206361], Nov., 1958. 35 pp. 22 refs. Investigation of a wide class of variational problems of interest in rocket flight. Results are reviewed with particular regard to such topics as optimum thrust programing for level flight, vertical flight, and for arbitrarily inclined rectilinear trajectories. A general theory of the optimum flight paths of rocket-powered aircraft, missiles, and satellite carriers is formulated. Solutions for important particular cases and special types of flight are obtained in closed form. Computational methods are supplied for several types of boundary value problems.

PHYSICS

POLARIZABILITY OF HYDROGEN AT HIGH TEMPERATURES. W. C. Marlow, III, and A. Kamradt. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 85-111. 19 refs. Investigation of the polarizability of a hydrogen gas with temperature, pressure, and frequency. The problem separates into two temperature regions, that of dissociation and of excitation and ionization. For the region of dissociation, the mean polarizability is given as a function of the degree of dissociation. To determine the mean polarizability in the region of excitation and ionization, it is necessary to know the population densities of the excited states and the degrees of ionization. These factors are calculated using the Urey-Fermi covolume technique. Preliminary calculations for the frequency-dependent polarizability are given, including an order-of-magnitude calculation of the contribution from permanent dipoles. Finally, the contribution of the free charges to the frequency-dependent polarizability is considered.

POWER PLANTS

PHOTOCHEMISTRY OF THE UPPER ATMOSPHERE AS A SOURCE OF PROPULSIVE POWER. A. F. Charwat. ARS J., Feb., 1959, pp. 108-114. 22 refs. Analysis of an oxygen recombination ram-jet for propulsion in the Earth's upper atmosphere. Its performance depends on the chemical kinetics of the oxygen recombination reaction, the aerothermodynamics of the ram-jet cycle, and the rarefied gas aerodynamics. Outside of a limited flight range, these phenomena imply the existence of mutually exclusive conditions. Near-orbital speeds appear to be unattainable, and only low supersonic flight is possible if appropiate catalysts to accelerate the reaction can be found. The performance of the engine depends primarily on the flight Mach Number. Internally supersonic recombination is impractical because of excessive recombination times required to complete the re-

action, whereas catalysis necessarily implies stagnation conditions in the reaction zone.

ION ROCKET ENGINE SYSTEMS - A SUMMARY. R. H. Boden. Aero/Space Engrg., Apr., 1959, pp. 65-71, 75. Evaluation of the concept of an ion rocket engine and definition of the problem areas including the heat source, the power converter, the thrust chamber, and the propellants. The overall requirements of these components are examined and assumed missions to the moon or to Mars are discussed.

SOME DESIGN PARAMETERS OF A SIMPLIFIED ION ROCKET. H. Preston-Thomas. Brit. Interpl. Soc. J., Nov.-Dec., 1958, pp. 575-583. Derivation of equations presented previously in a study covering the design of ion rockets. The applicability of the method for investigating the properties of a simplified model is demonstrated. Equations are obtained for mass distribution, transfer times, and specific impulse for the cases of constant exhaust velocity and constant acceleration.

ACCELERATOR DESIGN TECHNIQUES FOR ION THRUST DEVICES. S. L. Eilenberg. North Am. Av. Rocketdyne R-1430, Feb. 12, 1959. 40 pp. AFOSR-supported analysis of ion accelerator design, which is complicated by the requirement that the ion beam must be allowed to escape from the electrode system. This requirement necessitates the inclusion of an aperture in one electrode which results in a weakening of the field, thus, reducing the total current. It is concluded that, depending upon the current required for a given mission, the ion thrust device could be made up of one or more barrel accelerators or slit accelerators shaped into any convenient configuration such as a set of concentric circles, a single circle, a spiral, or parallel strips. An estimate can be obtained from a proper choice of the effective value of the interelectrode space, d, or the ratio of the emitter area to d^2. Finally, a close approximation of the beam shape and charge distribution for an electrode configuration may be obtained from an electrolytic analog system.

Rocket

COMBUSTION IN LIQUID-FUEL ROCKET MOTORS. D. B. Spalding. Aero. Quart., Feb., 1959, pp. 1-27. Analysis of the processes occurring in liquid bipropellant rocket motors. Droplet vaporization, chemical reaction, and drag between gas and droplet are considered for a one-dimensional model. Quantitative theoretical results are presented for the variation of droplet size, droplet velocity, gas temperature, and gas velocity within the chamber. The theory is applied to the German V-2 rocket motor. Practical conclusions from, and extensions to, the theory are discussed.

ANALYTICAL INVESTIGATION OF THE SIGNIFICANCE OF TURBINE-INLET TEMPERATURE IN HIGH-ENERGY ROCKET TURBODRIVE APPLICATIONS. H. E. Rohlik. US, NASA Memo. 1-6-59E, Feb., 1959. 24 pp. Investigation of the effect of turbine-inlet temperature on gross weight for three high-energy long-range rockets. The method of analysis is described. Results indicate that the gross weight of the hydrogen-reactor system is more sensitive to changes in turbine-inlet temperature than either the hydrogen-oxygen or the hydrogen-fluorine systems. Gross weight of the hydrogen-reactor system can be reduced by 2.6% by the use of cooling and a turbine-inlet temperature of 3,000°R. The reductions in the first stages of the hydrogen-oxygen and hydrogen-fluorine systems were 0.7% and 0.2%, respectively. None of the systems investigated showed gains warranting the use of turbine cooling.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

THE TAILORED-INTERFACE HYPERSONIC SHOCK TUNNEL. Ch. E. Wittliff, M. R. Wilson, and Abraham Hertzberg. (ASME-ARS Av. Conf., Dallas, Mar. 16-20, 1958.) J. Aero/Space Sci., Apr., 1959, pp. 219-228. 50 refs. AFOSR-supported discussion of the "tailored-interface" method as applied to a shock tunnel. In the "tailored-interface" modification, the incident shock wave is reflected at the downstream end of the shock tube, and conditions of the driver and driven gases at the interface are matched (or "tailored") so that no additional waves are created by the interaction of a reflected shock and the interface. The method provides a longer testing time than a conventional shock tunnel, and, hence, a means of alleviating flow unsteadiness in the test section caused by shock-wave attenuation. Various gasdynamic phenomena associated with shock tunnels are discussed. Illustrating the research application of the method, results of heat transfer experiments on a hemisphere-cylinder model are presented and compared with theory.

ROTATING WING AIRCRAFT, HELICOPTERS

HELICOPTER GROUND RESONANCE. W. E. Hooper. Aircraft Eng., Feb., 1959, pp. 32-39. Evaluation of the equations of motion developed by Coleman for a particular helicopter configuration and a large number of different combinations of rotor and fuselage damping. The results reveal the dependence of the unstable range on rotor and fuselage damping. Both viscous and friction rotor dampers are considered.

SPACE TRAVEL

SOME CONSEQUENCES OF A THEORY OF THE RADIATION BELT. S. F. Singer. (9th Internatl. Astron. Congr., Amsterdam, Aug. 25-30, 1958.) Brit. Interpl. Soc. J., Nov.-Dec., 1958, pp. 558-564. Summarized presentation of the results of a theory giving the origin of the radiation, its nature and energy, and its distribution around the Earth with latitude and with altitude. A discussion is presented on its consequences for studies of the outer atmosphere of the Earth, the planets, and Moon; particular attention is paid to space medical implications and means of protection against the radiation. The most promising counter-measure

appears to be "sweeping out" of the radiation. Some new experiments to test the trapping properties of the Earth's magnetic field are suggested.

INTERPLANETARY DUST DISTRIBUTION. D. B. Beard. Lockheed Aircraft Missile Systems Div. TR LMSD-48381, vol. III, Jan., 1959, pp. 211-232. 16 refs. Analysis of dust-scattered light at very small elongations from the sun (2 to 10 solar radii) reveals that the dust is distributed as $r^{-\nu}$, where r is the distance from the sun and ν is some number possibly less than 1.5 but probably equal to it. The minimum radius of the dust particles is found to be a few microns and the particle concentration depends on the particle radius. The concentration of dust at the earth's orbit approximates 10^{-14} to 10^{-15} particles/cu.cm.; and because of the earth's gravitational field, the concentration at the earth's surface may be increased to as much as 10^{-10} to 10^{-11} particles/cu.cm. Interpretation of the spatial and temporal fluctuations of the zodiacal light confirms the probable existence of a dust blanket around each of the planets.

ON THE MOTION OF ARTIFICIAL SATELLITES TAKING INTO ACCOUNT THE RESISTANCE OF THE MEDIUM. M. M. Niţă. Rev. Méc. Appl., No. 1, 1958, pp. 57-76. 12 refs. (Also in Stud. Cerc. Mec. Aplic., No. 2, 1958, pp. 337-358.) Study of the motion of artificial satellites under the assumption of a perfectly spherical, homogeneous, fixed, and completely isolated in space earth. The process of integration for the differential equations of motion is described. The laws governing the motion of a satellite are derived, with the position and speed being determined at any time. A method of calculation is also indicated for the case of a satellite moving through inhomogeneous media.

SATELLITE ORBIT MECHANICS. Harry Esses. Aero/Space Engrg., Apr., 1959, pp. 48-54. Study of the fundamental theory of satellite orbits and illustration of the theory by numerical data presented in graphical form. The four possible orbit types for a particle moving in the gravitational field of a fixed point mass are the ellipse, the circle, the parabola, and the hyperbola. All of these are discussed in terms of the eccentricity. Emphasis is placed on the elliptical orbit, and the geometrical and dynamic parameters of such an orbit are outlined, as are expressions for the perigee, apogee, orbital velocity at any point in the orbit, and period. In addition, and experiment on Einstein's generalized relativity theory is outlined.

THEORY OF THE EFFECT OF DRAG ON THE ORBITAL INCLINATION OF AN EARTH SATELLITE. J. P. Vinti. J. Res., Feb., 1959, pp. 79-88. Analysis of the effect that rotation of the earth's atmosphere has on the inclination of the orbit of a satellite. It is assumed that the drag is in the direction of the air velocity relative to the satellite and that its magnitude diminishes so rapidly with altitude that it is appreciable only near perigee in an elliptic orbit. Without further assumptions about the properties of the drag function, results are then deduced for the secular changes in inclination up to, but not including, the final ballistic stage of motion.

SATELLITENBEWEGUNG MIT REIBUNG. L. N. Persen. ZAMM, Nov.-Dec., 1958, pp. 437-442. In German. Study of the motion of artificial satellites covering two cases: (a) the frictional force is proportional to the square of velocity and inversely proportional to the distance r from the center of mass of the planet; (b) the frictional force is proportional to the velocity and inversely proportional to the square of the distance r. It is shown that, in both cases, rigorous solutions for the path of the satellite can be obtained in terms of known functions. Singer's approach, stating the tendency of the satellite path to become circular before the spiral course toward the planet is entered, is discussed in detail. The lifetime of the first Soviet satellite is determined, and the theoretical bases used in the calculation are stated.

STRUCTURES

Beams & Columns

LIMIT DESIGN FORMULAS FOR THIN-WALLED COLUMNS AND APPLICATION TO REDUNDANT STRUCTURES. S. Krishnan and K. V. Shetty. Aero. Soc. India J., Nov., 1958, pp. 57-62. Presentation of a method by which an optimum design for a redundant column member can be obtained on the basis of simultaneous plastic and local buckling. It is noted that such a condition is possible only for short column members having high thickness/width ratios. For determining the local buckling stress under plastic conditions, Bijlaard's coefficient is applied to the empirical local buckling stress relations for typical sections proposed by Needham as a result of extensive experimental study. The thickness/width ratios derived by equating the local buckling stress to the yield stress are substituted in the load-deformation relationship, and a family of load-deformation curves is plotted, covering a range of thicknesses. It is shown how these curves may be used to determine the optimum section for a redundant column member which is expected to withstand a given load under conditions of plastic yielding and large deformation.

Cylinders & Shells

AXIALLY-SYMMETRICAL PROBLEMS OF THERMO-ELASTICITY FOR A CYLINDER OF UNLIMITED LENGTH. M. Sokołowski. Acad. Pol. Sci. Bul., Tech. Sci. Ser., No. 4, 1958, pp. 207-210. Presentation of two solutions for stresses and displacements, the first being for the general case of a sourceless field of temperature, and the second considering a linearly-distributed source of heat. Solutions are presented by applying a function of strain consisting of the potential of thermoelastic strain $\phi(r, z)$ and Love's function $\Psi(r, z)$, as well as the mathematical apparatus of Fourier's cosinusoidal transform and Hankel's finite transform.

Plates

THE GENERAL SOLUTION FOR A RECTANGULAR ORTHOTROPIC PLATE EXPRESSED BY DOUBLE TRIGONOMETRIC SERIES. Piotr Wilde. Arch. Mech. Stosowanej, No. 5, 1958, pp. 747-754. Derivation of formulas for the Fourier coefficients of the deflection surface of a plate with arbitrary boundary conditions by means of the Fourier transformation. The differential equation is then transformed into an algebraic equation. The deflection surface is represented in a double trigonometric series.

ANALYSIS OF PANELS WITH BONDED, HAT-SHAPED STIFFENERS, LOADED IN SHEAR. Appendix A - DETERMINATION OF THE RANGE OF APPLICATION OF THE APPROXIMATE FORMULAS IN AIRCRAFT DESIGN. Appendix B - NUMERICAL EXAMPLE. J. P. Benthem and J. v.d. Vooren. Netherlands, NLL TN S. 520, Feb., 1958. 18 pp. Presentation of a solution for the distribution of shear flow in order to obtain equations for the effective panel thickness and the maximum shear stress in the glue layer. The formula for the effective panel thickness gives values which are about 5% too high, but are suitable for design purposes. The ratio between the maximum shear stress in the glue layer and the undisturbed shear stress in the panel varies between 0.24 and 0.55 for the various stiffener-skin configurations given.

COMPUTATION BY MEANS OF POLYNOMIALS OF INFLUENCE SURFACES FOR ANISOTROPIC PLATES WITH FINITE DIMENSIONS. Marian Suchar. Arch. Mech. Stosowanej, No. 5, 1958, pp. 615-634. 14 refs. Analysis to obtain polynomials from which the regular parts of the influence surfaces can be determined. Quasi-biharmonic polynomials are obtained as a particular case of the (A)-polynomials previously calculated. The illustrative example presented covers a system of algebraic equations for the determination of decomposition coefficients, based on a finite number of members and using the method of least quadratic irregularity for the orthotropic plate having the shape of a parallelogram, simply supported along two edges, the remaining sides being free.

DYNAMIC LOAD CARRYING CAPACITY OF A CIRCULAR PLATE. Piotr Perzyna. Arch. Mech. Stosowanej, No. 5, 1958, pp. 635-647. Analysis showing to what extent the dynamic load carrying capacity of a thin circular plate simply supported on the edge depends on the variability of the pressure as a function of time. The method of Symonds for beams is applied to two different cases: (a) that of moderate pressure and (b) that of high pressure when the plate becomes plastic.

THE ANALYSIS OF SINGULARLY LOADED AND RIGIDLY CLAMPED THIN ELASTIC SLABS WITH CURVILINEAR BOUNDARIES. I. W. A. Bassali. Cambridge Philos. Soc. Proc., Jan., 1959, pp. 121-136. 22 refs. Application of the complex variable methods to derive exact solutions in closed form for small deflections of certain thin elastic plates due to transverse concentrated forces or couples applied at arbitrary or specified points. The isotropic plates are considered bounded by curvilinear edges of certain types along which the plates are rigidly clamped. Plates bounded by curves having the form of the inverse of an ellipse with respect to its center or its focus are included as special cases.

A THIN CIRCULAR PLATE NORMALLY AND UNIFORMLY LOADED OVER A CONCENTRIC ELLIPTIC PATCH. W. A. Bassali and M. Nassif. Cambridge Philos. Soc. Proc., Jan., 1959, pp. 101-109. 10 refs. Analysis concerning the small transverse displacement of a thin circular plate elastically restrained along the circular boundary and subject to uniform normal pressure distributed over the area of an ellipse concentric with the plate. The method of complex potentials is used, and the general assumptions relating to the small deflection theory of thin plates are adopted. Explicit formulas for the bending and twisting moments and shearing forces are given at any point on the boundary and at the center of the plate.

Thermal Stress

THERMAL STRESSES IN RECTANGULAR PLATES. J. S. Przemieniecki. Aero. Quart., Feb., 1959, pp. 65-78. Application of the characteristic functions for beam vibration modes to derive an approximate solution for the calculation of thermal stresses in rectangular isotropic flat plates subjected to arbitrary temperature distributions in the plane of the plate and constant temperature through the plate thickness. The thermal stresses are obtained in the form of generalized Fourier expansions in terms of the characteristic functions and their derivatives, which represent normal modes of vibration of a beam clamped at both ends.

THE STRESSES DUE TO A NUCLEUS OF THERMOELASTIC STRAIN IN A SEMI-INFINITE PLATE CONTAINING A SEMICIRCULAR NOTCH. Józef Ignaczak. Arch. Mech. Stosowanej, No. 5, 1958, pp. 707-713. Presentation of a solution to the problem of thermal stress due to a nucleus of thermoelastic strain in the neighborhood of a unique semicircular notch. The solution obtained has the form of a series of coefficients that are determined from a linear infinite system of algebraic equations.

THERMAL STRESSES IN A BOX STRUCTURE. B. M. Lempriere. Coll. of Aeronautics, Cranfield, Note No. 84, July, 1958. 12 pp. Analysis using an energy method to determine the thermal stresses in a finite-length box structure resulting from uniform skin heating. The solution depends upon an eighth order differential equation with constant coefficients.

Tubes

TORSION OF SEMI-ELLIPTIC AND HOLLOW-ELLIPTIC SECTIONS. P. M. Quinlan. Natl. U.

Ireland, U. Coll., TN 4 (AFOSR TN 58-883) [AD 203905], July, 1958. 23 pp. Application of conformal mapping to reduce the torsion problem for hollow-elliptic and semielliptic sections to a potential problem in a rectangle. In each case, both the appropriate stress function and the torsional rigidity are obtained in series form, and the appropriate asymptotic form of the series for the stress components is given for use where greater precision is required. Solutions developed for the hollow-elliptic tube and the prolate semielliptic shaft check with existing solutions obtained by other methods. Calculations are performed to evaluate the effects of cracking on the sections, and the results are presented in tabular form.

Wings

STRESS DISTRIBUTION IN MULTI-CELLULAR TORQUE BOXES DUE TO PRIMARY AND SECONDARY CREEP. K. A. V. Pandalai and S. A. Patel. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 480 (AFOSR TN 58-1074) [AD 207243], Dec., 1958. 22 pp. Description of a stress analysis using an elastic analog to reduce the creep problem to one of nonlinear elasticity. The governing equations for the determination of shear flow in the torque box are derived. Particular examples for two-cell and three-cell boxes are solved numerically, and the results for shear flow and torque carried by each cell are plotted against the creep exponent which is a function of temperature. Results indicate that the stress distribution and deformation due to creep can differ appreciably from that of the linear, elastic theory; the factors influencing this deviation being the geometry of the torque-box and the temperature.

EFFECTS OF CROSS-SECTIONAL SHAPE, SOLIDITY, AND DISTRIBUTION OF HEAT-TRANSFER COEFFICIENT ON THE TORSIONAL STIFFNESS OF THIN WINGS SUBJECTED TO AERODYNAMIC HEATING. Appendix A - REDUCTION IN TORSIONAL STIFFNESS OF A MODIFIED DOUBLE WEDGE. Appendix B - REDUCTION IN TORSIONAL STIFFNESS OF A MULTIWEB WEDGE. Appendix C - EFFECT OF A VARIABLE HEAT-TRANSFER COEFFICIENT ON REDUCTION OF TORSIONAL STIFFNESS. R. G. Thomson. US, NASA Memo. 1-30-59L, Feb., 1959. 31 pp. Study indicating that the flattening of a solid double wedge decreases the reduction in torsional stiffness, while slight degrees of blunting increase the loss. The influence of chordwise variations in heat-transfer coefficient due to turbulent and laminar boundary-layer flow on the torsional stiffness of solid wings is negligible. The effect of a step transition in heat-transfer coefficient along the chord of a solid wing can become appreciable. The torsional-stiffness reduction of multiweb and hollow double-wedge wings is substantially less than that calculated for a solid wing subjected to the same heating conditions.

THERMODYNAMICS

Combustion

FLAME STRUCTURE STUDIES. IV - PREMIXED CARBON MONOXIDE COMBUSTION. Raymond Friedman and R. G. Nugent. Atlantic Res. Corp., Squid TR ARC-3-P [AD 156505], Apr., 1958. 18 pp. Investigation making use of temperature and composition traverses made in lean CO-O flames with small proportions of added hydrogen and water vapor. The flame reaction consisted of a rapid step associated with intense luminosity, followed by a much slower process in which the last of the CO was consumed. Hydrogen and water vapor are not interchangeable as additives for the lean CO-O flames. The hydrogen additives give a higher burning velocity and a more rapid second stage reaction.

OPTICAL STUDIES OF THE STRUCTURE OF TURBULENT FLAMES. Kurt Wohl and R. H. Atalla. U. Del., Squid TR DEL-11-P [AD 156948], Apr., 1958. 20 pp. Investigation to decide which of two models, fluctuating laminar flame front or homogeneous expanded reaction zone, prevails at conditions of turbulence ordinarily encountered. Traverses of the various types of visible radiation and of infrared water vapor radiation through three propane-air flames are compared.

FLOW FIELD OF A FLAME IN A CHANNEL. M. S. Uberoi. Phys. Fluids, Jan.-Feb., 1959, pp. 72-78. Study in which a stationary flame is stabilized in a two-dimensional channel in such a way that it closely corresponds to the case of a flame propagating in a channel. The entire flow field of unburned and burned gases is mapped by taking stroboscopic photographs of small particles suspended in the combustible gases. The asymptotic flow field of the burned gases is analyzed in terms of flow conditions of the flame. The possibility of obtaining an analytic flow field on the basis of constant flame speed is examined. It appears that no solution exists unless the channel walls in the region of burned gases are displaced inward. It is observed that the convex flames are possible and concave ones impossible within the framework of a theory based on constant flame speed.

THE STUDY OF FLOW AND REACTION RATES IN TURBULENT FLAMES. R. P. Barbor, J. D. Larkin, and C. W. Shipman. U. Del., Squid TR DEL-8-P [AD 147703], Dec., 1957. 38 pp. Investigation of the feasibility of using reaction rates as a function of position within turbulent flames as an approach to the problem of flame propagation. Static and impact pressure measurements and chemical composition analyses are made in the burning zones of two simulated ram-jet combustion chambers. The method presents one approach to the propagation problem by relating the reaction rate to mean flow patterns which may change through the burning zone.

COMPOSITION TRAVERSES IN CURVED LAMINAR FLAME FRONTS. G. H. Markstein. Cornell Aero. Lab., Squid TR CAL-75-P [AD 156503], Apr., 1958. 21 pp. 21 refs. Measurements of composition profiles in curved regions of laminar flame fronts indicate shifts of composition and temperature in qualitative agreement with predictions based on a transport process across flow

lines. The results are compatible with the changes of burning velocity required by fluid dynamics analysis. The lack of an adequate theory of the structure of two-dimensional flame fronts precludes at present a quantitative evaluation of the results of transport processes.

ON THE STRUCTURE OF DETONATION WAVES. T. C. Adamson. U. Mich., Squid TR MICH-4-M [AD 156509], Apr., 1958. 19 pp. Analysis considering a standing, normal detonation wave to determine whether the shock-produced temperature jump is sufficient in itself in order that the heat transfer be negligible, or whether the heat transfer mechanism is important enough to be included in any calculation. The wave is assumed to be a shock followed by combustion, and the reaction is assumed to be a first order reaction following the Arrhenius rate law.

IONIZATION IN DETONATION WAVES. Satyaki Basu and J. A. Fay. MIT, Squid TR MIT-17-P [AD 156502], Apr., 1958. 16 pp. 14 refs. Measurement of the electrical conductance of stoichiometric oxy-hydrogen detonation waves with initial pressures of 1/10 to 1 atm. and of oxy-acetylene detonation waves at 1 atm. initial pressure. Equilibrium ionization appeared to be achieved in detonation waves in the mixtures tested. Nitrous oxide (NO^+) formation dominated the ionization in the oxy-hydrogen detonation waves. The gas conductance for the oxy-acetylene waves with 66% C_2H_2 in the initial mixture corresponded to homogeneous rather than total equilibrium. At richer mixtures, the conductance was higher than the theoretical one by a factor of about ten.

Heat Transfer

HEAT TRANSFER BY FREE CONVECTION WITH NATURAL COUNTER-FLOW BETWEEN LIQUID AND THE INSIDE WALLS OF VERTICAL PASSAGES. S. A. Guerrieri, C. V. Foster, and L. L. Saphier. U. Del., Squid TR DEL-7-R [AD 145988], Oct., 1957. 87 pp. 18 refs. Investigation of free convection with natural counterflow between liquids and the inside walls of vertical tubes. Water, oil, and normal butane are studied inside 12-in. vertical tubes of 0.50, 0.75, 1.0, and 3.0 in. Flow rates and inlet and outlet temperatures of the heating and cooling fluid streams are taken. The heat transfer results are presented as plots of the Nusselt Number (N_{Nu}) versus the product of the Grashof Number (N_{Gr}) and the Prandtl Number (N_{Pr}). The product of (N_{Gr}) and (N_{Pr}) was varied over a range from 10^{10} to 3×10^{14}. Below 5×10^{11} the data may be fairly well represented by published correlations for vertical flat plates in air; in the higher ranges, the data lie near a line parallel to, but almost above, the Eckert-Jackson semiempirical equation.

THE ANALYTICAL DETERMINATION OF THE LOCAL HEAT TRANSFER CHARACTERISTICS OF GASES FLOWING TURBULENTLY IN THE THERMAL ENTRANCE REGION OF A CIRCULAR DUCT WITH LARGE TEMPERATURE DIFFERENCES BETWEEN THE GAS AND THE DUCT WALL. Helmut Wolf and M. J. Zucrow. Purdue U., Squid TR PUR-35-M [AD 156180], Dec., 1957. 47; 42; 38; 44; 39 pp. Analysis of flow with heat transfer for a fluid flowing through a circular duct of constant area under laminar and turbulent flow conditions. Calculations are made of the heat transfer characteristics for air and CO_2 in the entrance region and of local values of the Nusselt Number and friction coefficient at nominal values of Reynolds Number. The intensity of heating or cooling caused a larger change in the local Nusselt Number for air than CO_2 under similar conditions of flow at a given axial position.

DETAILS OF EXACT LOW PRANDTL NUMBER BOUNDARY-LAYER SOLUTIONS FOR FORCED AND FOR FREE CONVECTION. E. M. Sparrow and J. L. Gregg. US, NASA Memo. 2-27-59E, Feb., 1959. 45 pp. 13 refs. Presentation of exact numerical solutions considering (1) forced convection over a flat plate for uniform wall temperature and uniform wall heat flux, and (2) free convection over an isothermal vertical plate. Heat transfer and shear-stress characteristics, as well as temperature and velocity distributions are presented. The heat-transfer results are correlated in terms of dimensionless parameters varying only slightly over the entire liquid-metal range. A comparison of previous analytical and experimental work with the new exact solutions is made.

RELAXATION PHENOMENA IN FLOW PROBLEMS. Andrzej Szaniawski. Arch. Mech. Stosowanej, No. 5, 1958, pp. 671-698. 11 refs. Study considering the influence of relaxation phenomena on the establishment of general equations of fluid motion. The analysis uses the methods for the thermodynamics of irreversible processes introduced by Onsager. The basic assumption states that the number of parameters for the state of equilibrium differs from that of the state of perturbation. In the latter case, the temperature is not determined and the entropy is calculated by means of the methods of statistic thermodynamics.

VTOL & STOL

SEMIEMPIRICAL PROCEDURE FOR ESTIMATING LIFT AND DRAG CHARACTERISTICS OF PROPELLER-WING-FLAP CONFIGURATIONS FOR VERTICAL- AND SHORT-TAKE-OFF-AND-LANDING AIRPLANES. R. E. Kuhn. US, NASA Memo. 1-16-59L, Feb., 1959. 38 pp. 26 refs. Development of semiempirical expressions using the momentum theory for calculating the effect of propeller thrust and slipstream. The method uses measured power-off, forward-speed data and measured slipstream deflection data at zero forward speed to provide a basis for estimating the lift and drag at combined forward speed and power-on conditions. A correlation of slipstream deflection data is included and a comparison of experimental data with calculated results is made. The procedure is applicable only in the unstalled flight regime, but could be used in preliminary design estimates of the performance to be expected of VTOL and STOL aircraft.

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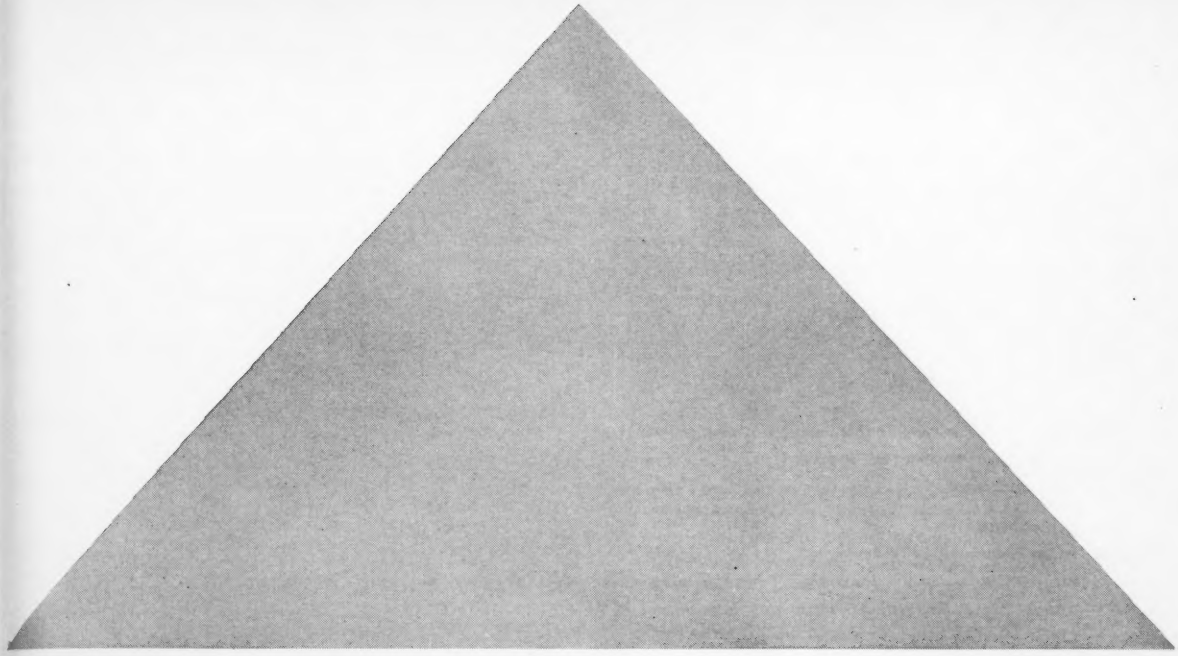

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Aircraft Timber. V—Glues and Synthetic Cements. D. W. Richardson. *SLAE J.*, Dec., 1958, pp. 7–14.

Choosing and Using Rubber-Base Adhesives. R. K. Humke. *Mach. Des.*, Jan. 8, 1959, pp. 128, 129, 132–136.

Untersuchungen von Glasfaserpolyester-Kunststoffen zur Verwendung im Flugzeug- und Fahrzeugbau. H. Winter, G. Niederstadt, and W. H. Boehm. *DFL Inst. Flugzeugbau Bericht No. 97; No. 97b*, 1958. 88; 134 pp. 639 refs. In German. Description of experimental investigations to establish production and testing techniques. Tests cover laminated fabrics of various constructions, and the tensile strength, elasticity, as well as the effect of humidity and residual stresses are determined. Includes extensive survey of the literature.

Progress in High Temperature Resins: Epoxy Novolacs. D. D. Applegath, R. F. Helmreich, and G. A. Sweeney. *SPE J.*, Jan., 1959, pp. 38–42. Discussion of properties of a new resin which combines the thermal stability of novolacs with the fabricating ease of conventional epoxy resins.

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A Photo-Electric Load Monitor for Rapid Tensile Testing. B. F. Billing. *Gt. Brit. RAE TN Met. 293*, July, 1958. 8 pp.

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The Coexistence Problem for Hill's Equation. Appendix—The Classification of Linear Differential Equations. S. Winkler and W. Magnus. *NYU Inst. Math. Sci. Div. Electromagn. Res., Res. Rep. BR 26* (*AFOSR TN 58-660*) [*AD 162191*], July, 1958. 91 pp. 48 refs. Investigation of Hill's equation with a coefficient of period π. The coexistence of two linearly independent solutions with period π or 2π is considered, as well as the cases of a four-parametric equation which can be transformed into an equation of Hill's type. The existence of solutions admitting a terminating Fourier expansion is investigated, and partial answers are provided.

On a Lemma of U. V. Linnik. A. Devinatz. *Wash. U. (St. Louis), Dept. Math. Rep.* (*AFOSR TN 58-552*) [*AD 158370*], July 17, 1958. 3 pp.

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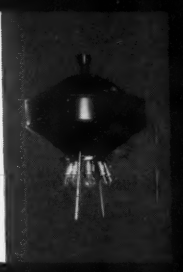

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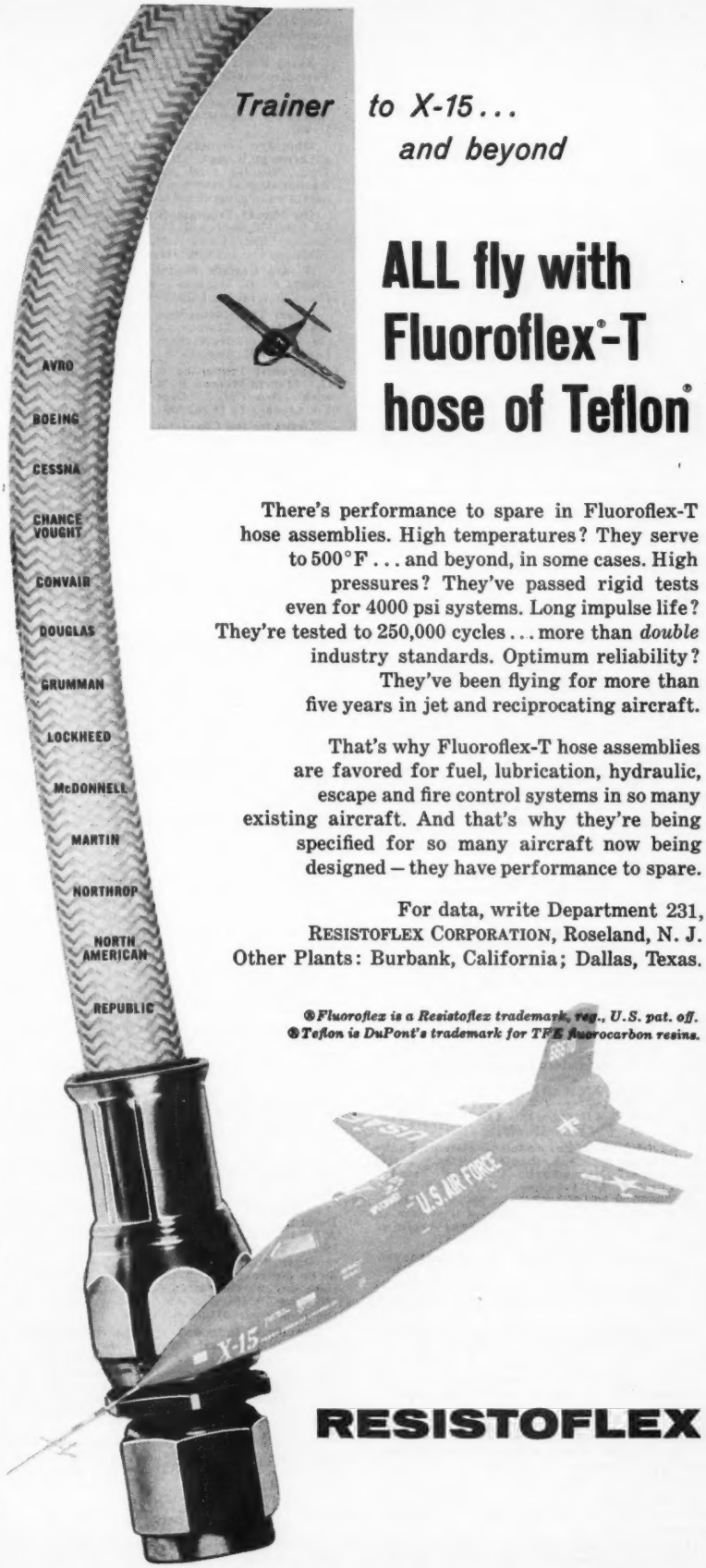
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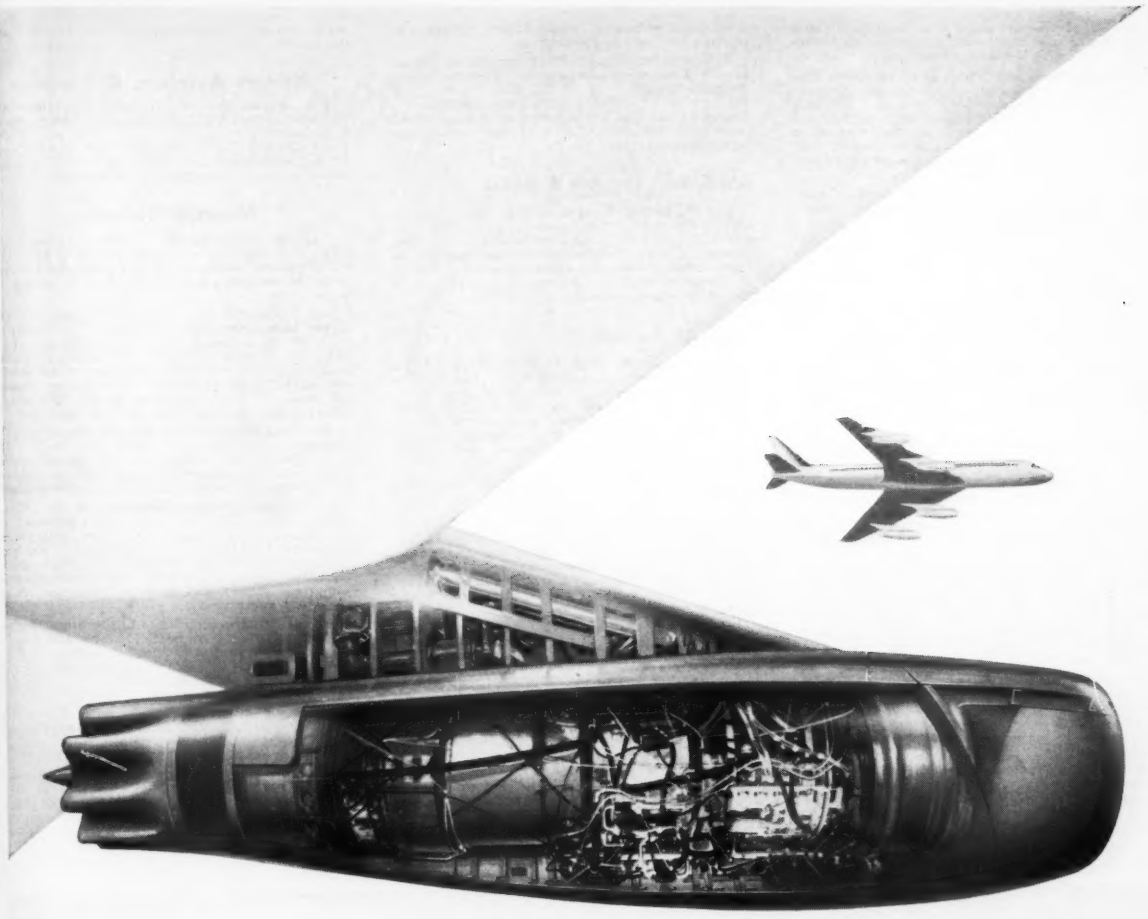

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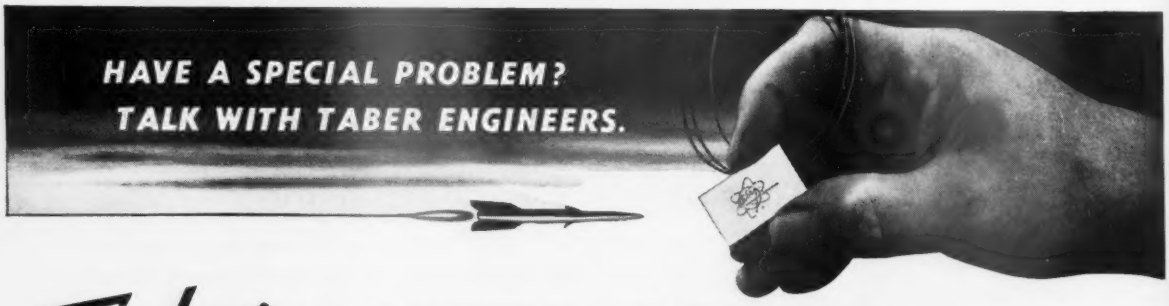

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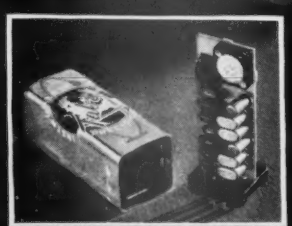

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Career Opportunities at NASA

NASA directs and implements the Nation's research efforts in aeronautics and the exploration of space for peaceful purposes and the benefit of all mankind. We offer unique opportunities in basic and applied research to scientists and engineers with degrees in the various disciplines.

Briefly described here are representative current NASA programs. Openings exist in all of these programs, at the facilities named.

SPACE TECHNOLOGY

Space vehicle development, including basic planning, development, contract coordination, and operational programming and planning for manned and unmanned satellites. Systems studies for auxiliary power supplies, air regenerative systems, instruments, guidance and communication equipment for space vehicles.

Space probes: Development and operation of vehicles, payload and instrumentation, programming and operation of flight, trajectory, communication systems, and ground support systems for near space and deep space probes.

Beltsville

SPACE MECHANICS

Experimental and analytical study of orbital mechanics including parameters of preliminary and refined orbits, ephemerides, lifetimes, equator crossings and perturbations.

Beltsville; Langley; Ames

PROPULSION AND PROPULSION SYSTEMS

Developmental studies of boosters, launchers, multi-stage engines, guidance and attitude control systems for space vehicles.

Basic research on the interrelationships between electrical, magnetic and thermodynamic energy, and application of such knowledge to space propulsion.

Magneto hydrodynamics: Research on plasma and ion accelerators for space propulsion and auxiliary power systems.

Research on reactors and reactor shielding for aeronautical and space propulsion systems.

Beltsville; Lewis

AERODYNAMICS AND FLUID MECHANICS

Investigation of the thermodynamics and transport properties of gases at high temperatures as encountered in entry into planetary atmosphere.

Research on performance, stability and control, automatic guidance, and navigation for subsonic, supersonic, and hypersonic aircraft.

Aerodynamic heating and satellite re-entry phenomena.

Langley; Ames; Lewis; High-Speed Flight Station

(Positions are filled in accordance with Aeronautical Research Announcement 61B)

INSTRUMENTATION AND COMMUNICATION

Research and development of new sensing devices and instrumentation techniques in electronics, optics, aerodynamics, mechanics, chemistry and atomic physics.

Systems studies and evaluation of control, guidance, navigation, and communication equipment for space vehicles and other high performance applications requiring rugged and compact design.

All Facilities

GEOPHYSICS, ASTRONOMY AND ASTROPHYSICS

Experimental programs and evaluation studies of astronomical and geophysical measurement and scientific equipment used in space vehicle payloads.

Studies of fields and particles in space, investigations of the composition of planetary atmospheres, and development of instrumentation and experimental techniques for these investigations.

Beltsville

STRUCTURES AND MATERIALS

Investigation of the characteristics of high temperature structures and materials. Study of fatigue, structural stability, and other problems of structural dynamics.

Solid State Physics: Study of the elementary physical processes involved in mechanical behavior of materials, such as fractures; the nature of the corrosion process; and physical-chemical relationships governing behavior of materials.

Langley; Ames; Lewis

MATHEMATICS

Application of advanced mathematical techniques to the solution of theoretical problems in aeronautical and space research, involving the use of large modern computing equipment.

All Facilities

RESEARCH FACILITY ENGINEERING

Translation of research specifications into complete experimental facilities, involving mechanical, electrical, structural, architectural and machine design, and construction engineering.

Langley; Ames; Lewis

Please address your inquiry concerning any of the programs listed here to the Personnel Director of the appropriate NASA research center:

Langley Research Center, Hampton, Virginia
Ames Research Center, Mountain View, California
Lewis Research Center, Cleveland, Ohio
High-Speed Flight Station, Edwards, California
Beltsville Space Center, 4555 Overlook Ave., Washington, D. C.

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Power Plants

A Look at Rocket Propulsion for the Next 25 Years. T. F. Dixon. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-54.* 11 pp. 22 refs. Members, $0.50; nonmembers, $1.00. (Also in *Aero/Space Engrg.*, Feb., 1959, pp. 35–39.)

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Runs Quiet, Lands Short. *Ryan Reporter*, Dec. 17, 1958, pp. 20, 21, 24, 25. Description of a test program leading to the development of a successful noise suppressor and thrust brake.

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Thrust Control of Solid Propellant Rockets. H. W. Ritchey. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-55.* 7 pp. Members, $0.50; nonmembers, $1.00. Discussion of the fundamental principles of three types of thrust control: thrust vector control, thrust termination, and thrust modulation. Various methods for achieving these controls are also discussed.

Production

De Havilland Comet; Series 4 Aircraft in Production at Hatfield and Chester. *Aircraft Prod.*, Jan., 1959, pp. 20–29. Discussion of production techniques, tooling, and assembly for the fuselage and mainplane.

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Automatic Flaw-Detection. *Aircraft Prod.*, Jan., 1959, pp. 2–5. Description of an automatic ultrasonic immersion technique.

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Reliability

Missile Reliability Now. T. H. Braunstein. *Ordnance*, Jan.-Feb., 1959, pp. 686, 687. Review of what has been done to maintain and improve the reliability of some "ready" missiles.

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Research, Research Facilities

The Impact of Astronautics on Environmental Testing. Ch. A. Mills. *Can. Aircraft Ind.*, Dec., 1958, pp. 15–17, 41, 42. Discussion of the various parameters that a hypothetical satellite would encounter from manufacture to final orbit in order to assess the environmental tests required.

Mesure et Enregistrement des Débits d'Air. A. Moutet and L. Nadaud. *La Recherche Aéronautique*, Nov.-Dec., 1958, pp. 35–42. In French. Description of a method of airflow measurement, based on the addition to the flow of a known amount of different auxiliary gas. The method is applied to the specific case of a plant supplying compressed air to combustion laboratories. It is shown that the technique provides safe and accurate results regardless of pressure, speed, and temperature conditions.

Flight Testing

New Concept in USAF Flight Test. H. V. Leonhardt. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-50.* 5 pp. Members, $0.50; nonmembers, $1.00. Description of the "category testing" concept and of its primary and secondary objectives.

The Manufacturer's Flight Test Philosophy. F. C. Rowley. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-72.* 6 pp. Members, $0.50; nonmembers, $1.00. Discussion of over-all objectives, the planning of programs, instrumentation, the first flight and early evaluations, the role of structural flight testing, and the integrated product evaluation.

Special Flight Testing for the Carrier Suitability of Naval Aircraft. R. M. Elder. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-49.* 9 pp. Members, $0.50; nonmembers, $1.00. Discussion on the compatibility requirements of aircraft with catapults, arresting gears, and the optical landing system currently in use on fleet carriers. These three devices are described and an evaluation of tests is made.

The Airplane as a Research Tool. W. C. Williams. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-79.* 11 pp. Members, $0.50; nonmembers, $1.00. Discussion showing the importance of manned flight research. The various flight test categories are outlined.

Wind Tunnels

Technique d'Essais de Soufflage dans la Soufflerie de Cannes. A. Bevert. *La Recherche Aéronautique*, Nov.-Dec., 1958, pp. 7–10. In French. Description of equipment and techniques used in the wind tunnel at Cannes, France, for boundary-layer control studies.

IAS CORPORATE MEMBERS

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Equipement Transsonique des Souffleries de Recherches de l'O.N.E.R.A. M. Sirieix. *La Recherche Aéronautique*, Nov.-Dec., 1958, pp. 3–6. In French. Description of transonic wind-tunnel installations developed by ONERA, and survey of some experimental results.

Shock-Tube Testing Time. G. F. Anderson. *J. Aero/Space Sci.*, Mar., 1959, pp. 184, 185. Includes explanation of the difference between the actual and the theoretical test time.

Rotating Wing Aircraft, Helicopters

All-Weather Helicopter Systems. Walter Gerstenberger. (*Helicopter Assn. Gt. Brit. Meeting, London, Oct. 3, 1958.*) *Helicopter Assn. Gt. Brit. J.*, Dec., 1958, pp. 265–273; Discussion, pp. 273–281. Discussion of the progress made toward the realization of an all-weather helicopter. Various new features and operational characteristics are described.

Some Characteristics and Limitations of the Unloaded Rotor Compound Helicopter. F. L. Doblhoff. *AHS J.*, Jan., 1959, pp. 12–14. Comparisons between highly disc loaded VTOL aircraft and the unloaded rotor compound helicopter. Typical L/D ratios, speed limitations, weights, and payload characteristics encountered in the latter type are discussed.

A Wind-Tunnel Investigation of Rotor Behavior Under Extreme Operating Conditions with a Description of Blade Oscillations Attributed to Pitch-Lag Coupling. Appendix—**Lag Oscillations of Rotor Blades.** J. W. McKee and R. L. Naeseth. *U.S. NASA Memo. 1-7-59L*, Jan., 1959. 44 pp. Presentation of results in tabular form from an investigation on the behavior of a front rotor of a tandem helicopter during a pull-out maneuver.

Main Rotor Blade Design and Development. R. M. Kee. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–28.* 19 pp. 17 refs. Members, $0.50; nonmembers, $1.00. Discussion of the past and present status of metal extruded blades and some of the factors that have made interchangeable blades possible. Current trends in aerodynamic design are shown, as are the methods and test facilities employed in order to obtain information to substantiate the service life of present blades and improve the structural design of future blades.

Helicopter Stabilization and Handling Characteristics Improvement by Mechanical Means. Melvin Vague and Ch. M. Seibel. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–27.* 14 pp. Members, $0.50; nonmembers, $1.00. Discussion of mechanical and aerodynamic means used to provide dynamic stability in the YH-41 helicopter. Control trim changes accompanying variations in power are eliminated and control force trim provisions are refined.

Helicopter Vibration Investigations. D. Howe. *The Aeroplane*, Jan. 2, 1959, pp. 16–18. Discussion on various helicopter vibration problems and testing procedures for instability determination.

Safety

An Automatic Tumbling Aerofoil Delivery System and a Special Distress Beacon for Locating Crashed Aircraft. H. T. Stevinson and D. M. Makow. *Canada, NAE Quart. Bul.*, Oct. 1–Dec. 31, 1958, pp. 1–7. 12 refs.

Space Travel

Proposed Observations of the Martian Atmosphere. M. D. Ross. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–9.* 7 pp. Members, $0.50; nonmembers, $1.00.

The Balloon-Borne Capsule as a Space Flight Trainer. E. E. Beson. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–46.* 11 pp. Members, $0.50; nonmembers, $1.00. Discussion covering the need for a space trainer and the role of the rocket assisted capsule as the ideal space flight simulator. Design considerations are presented.

Trajectory Governs Moon Shot's Value. S. B. Kramer. *Av. Week*, Jan. 19, 1959, pp. 48, 49, 51, 55, 57. Discussion of the performance requirements of four types of trajectories for unmanned lunar probes: (1) orbiting the moon several times and (a) not returning to earth or (b) returning to earth or its vicinity; (2) pure impact or hard landing; (3) circumnavigating the moon once and returning to or near the earth; and (4) flying past, close to the moon, without returning.

Man-Machine Integration in Space Vehicles. G. W. Hoover. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1958, Rep. 59–51.* 11 pp. Members, $0.50; nonmembers, $1.00. (Also in *Aero/Space Engrg.*, Feb., 1959, pp. 54–58.)

The Problem of Escape from Satellite Vehicles. C. V. Carter and W. W. Huff, Jr. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–41.* 14 pp. Members, $0.50; nonmembers, $1.00. Discussion of such problem areas as: escape prior to take off; during boost at high dynamic pressure; during exit from, and entry into, the atmosphere; and during orbit. Design procedures which can be employed to determine a satisfactory escape system configuration are also presented.

Some Fundamental Problems Associated with Injecting, Orbiting and Recovering a Man from Orbit. R. C. Hakes. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–80.* 11 pp. Members, $0.50; nonmembers, $1.00. Comparison of the ballistic method and glide-type recovery methods, taking into account orbital considerations, capsule arrangements, launching system, control during orbit, and re-entry techniques. A design is shown for a capsule weighing about 2,500 lbs., which can be launched into orbit by a combination of existing boosters.

Systems Using Solar Energy for Auxiliary Space Vehicle Power. A. E. von Doenhoff and J. M. Hallissy, Jr. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59–40.* 15 pp. Members, $0.50; nonmembers, $1.00. Presentation of design requirements for an auxiliary power plant, and comparison in performance between a Rankine cycle-mercury system and a Stirling cycle-radium system. Direct conversion devices, such as the thermoelectric converter and the thermionic converter, are also discussed.

Retro-Rockets and Drag Devices Teamed for Satellite Recovery. F. W. Ross. *Space/Aeronautics*, Jan., 1959, pp. 180–184. Discussion of energy requirements for re-entry and recovery of satellites. A possible method using a combination of air drag and retro-rockets is outlined.

Guidance for Sputnik III. R. E. Stockwell. *Ordnance*, Jan.-Feb., 1959, pp. 673–675.

Satellite Ascent Paths. Ch. L. Keller. *Sperry Eng. Rev.*, Dec., 1958, pp. 2–14. Study of the development of the satellite ascent path from its first stage of merely orbiting to the more advanced steps of orbit selection and satellite interception. Problems of these further steps are discussed and typical methods of solution indicated.

Characteristic Velocity for Changing the Inclination of a Circular Orbit to the Equator. Leonard Rider. *ARS J.*, Jan., 1959, pp. 48, 49.

Structures

Bars & Rods

Kruchenie Tonkostennykh Sterzhnei Zamknutogo Profilia v Usloviiakh Neustanovivsheisia Polzuchesti. R. A. Aleksandrian, N. Kh. Arutiunian, and M. M. Manukian. *Prikl. Mat. i Mekh.*, Nov.-Dec., 1958, pp. 766–780. 13 refs. In Russian. Study of the torsion of thin bars having a closed profile subjected to the conditions of unsteady creep.

Beams & Columns

K-Value Formulas for Simplifying the Computations of Non-Uniform Beam Constants. Tsai Fang-Yin. *Scientia Sinica*, Dec., 1958, pp. 1,338–1,354. Presentation of the *K*-value formulas for computing the angle-change coefficient ϕ^a of six basic loading cases. Five examples of derived loading cases are given in tabular form.

Fully-Stressed Design of Elastic Redundant Trusses Under Alternative Load Systems. L. C. Schmidt. *Australian J. Appl. Sci*, Dec., 1958, pp. 337–348. Derivation of the conditions for minimum-weight design which are shown to require the determination of the minimum for all fully-stressed designs. The method enabling such designs to be found is presented together with two illustrative examples.

Cylinders & Shells

On Thermo-Elastic Stress-Strain Relations for Thin Isotropic Shells. P. M. Naghdi. (*J. Aero/Space Sci.*, Feb., 1959, p. 125.) *U. Mich. Res. Inst. TN 3 (AFOSR TN 58–994)* [*AD 205904*], Oct., 1958. 4 pp.

Elasticity & Plasticity

K Postroeniiu Teorii Ideal'noi Plastichnosti. D. D. Ivlev. *Prikl. Mat. i Mekh.*, Nov.-Dec., 1958, pp. 850–855. 11 refs. In Russian. Analysis of certain extremum properties of an ideal plastic flow in the case of Tresca's plasticity conditions.

Über die Verschiebungsfunktionen für das achsensymmetrische Problem der Elastodynamik. M. Predeleanu. *ZAMM*, Sept.-Oct., 1958, pp. 402–405. 11 refs. In German. Derivation of displacement functions for the axisymmetric problem of elastodynamics.

Ustoichivost' Ortotropnoi Tsilindricheskoi Obolochki pri Kruchenii s Vnutrennim Davleniem. V. M. Darevskii and S. N. Kukudzhanov. *AN SSSR Dokl.*, Nov. 1, 1958, pp. 49–52. In Russian. Study of the stability of an orthotropic cylindrical shell subjected to torsion with internal pressure.

O Rasprostranenii Uprugo-Plasticheskikh Voln pri Slozhnom Nagruzhenii. Kh. A. Rakhmatulin. *Prikl. Mat. i Mekh.*, Nov.-Dec., 1958, pp. 759–765. In Russian. Derivation of a solution for two problems covering the propagation of elasto-plastic waves in the case of complex loading in order to determine the dynamic resistance of materials.

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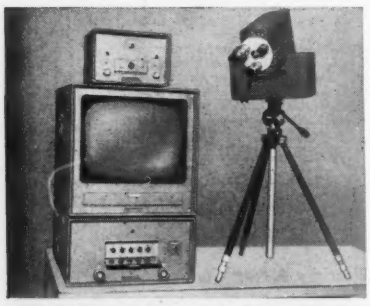

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gruzhennoi Krugloi Plastiny. N. F. Morozov. *AN SSSR Dokl.*, Nov. 21, 1958, pp. 417–419. In Russian. Determination of the uniqueness of the symmetrical solution for the problem of large deflections in symmetrically loaded circular plates.

Fatigue

Tenue à la Fatigue des Avions de Transport. J. Dor. *Tech. & Sci. Aéronautiques*, June, 1958, pp. 109–121. In French. Discussion covering the fatigue behavior of transport aircraft, with a description of the fail-safe system of structural design. The test program for selecting components and joining methods is also described.

Plates

A Half-Infinite Plate with an Elastically Restrained Edge. M. Stippes. *ZAMM*, Sept.-Oct. 1958, pp. 401, 402. Analysis of a more general condition of support along the edge of the plate, in which the Michell's solution is contained as a special case.

The Method of Successive Approximations Applied to Bending of Plates with Discontinuous Boundary Conditions. A. Kacner. *Acad. Pol. Sci. Bul.*, No. 5, 1958, pp. 251–254. Solution of the problem by applying the method of successive approximations in a manner elminating the adverse effect of the singularities of the influence function without resorting to integral equations in the open form.

Contribution to the Statics of Composite Plates. Václav Vodička. *Appl. Sci. Res., Sect. A*, No. 1, 1958, pp. 65–72. Mathematical determination of the static deflection of infinite composite plates. General results are applied to special cases.

Testing Methods

Tensile Strut-Testing Machines. A. H. Chilver. *RAeS J.*, Jan., 1959, pp. 57–59. Description of Fessler's arrangement for strut testing and of its advantages over conventional testing machines.

Thermal Stress

Correlation of Thermal Stresses in Circular Cylinders and Flat Plates. *The Engr.*, Jan. 9, 1959, pp. 56, 57. Presentation of numerical results for thermal stresses in hollow cylinders, lagged on the inner face, due to a step change in fluid temperature.

The Heating of Slabs with Arbitrary Heat Inputs. T. R. Goodman. (*Allied Res. Assoc. Rep.*, May 28, 1958.) *J. Aero/Space Sci.*, Mar., 1959, pp. 187, 188.

Thermodynamics

Combustion

Research on Supersonic Combustion. R. A. Gross. *ARS J.*, Jan., 1959, pp. 63, 64. AFOSR-supported review of experimental results, including steady strong detonations demonstrated for the first time in a laboratory.

A Novel Combustion Measurement Based on the Extinguishment of Diffusion Flames. A. E. Potter, Jr., and J. N. Butler. *ARS J.*, Jan., 1959, pp. 54–56. Description of a combustion measurement uniquely suited to the study of highly reactive fuel-oxidant combinations.

Vzaimodeistvie Udarnykh Voln s Frontom Plameni. S. M. Kogarko, V. I. Skobelkin, and A. N. Kazakov. *AN SSSR Dokl.*, Oct. 21, 1958, pp. 1,046–1,048. In Russian. Study of the problem covering the amplification of shock waves in the case of their interaction with the flame front affecting the change in the process of normal combustion in the shock wave.

A Detonation-Product Equation of State Obtained from Hydrodynamic Data. W. Fickett and W. W. Wood. *Phys. Fluids*, Nov.-Dec., 1958, pp. 528–534. 17 refs. Development of an equation of state from the following: (a) experimental measurement of the Chapman-Jouguet isentrope of detonation products together with (b) experimental detonation velocity vs. initial density curves.

K Voprosu o Vosplamenenii Adiabeticheski Nagretoi Gazovoi Smesi. S. G. Zaitsev and P. I. Soloukhin. *AN SSSR Dokl.*, Oct. 21, 1958, pp. 1,039–1,041. In Russian. Description of tests to study the generation and evolution of the exothermic reaction in homogeneous gaseous media heated adiabatically to temperatures of 600°–1,400°C. at pressures of 1–3 atm.

O Roli Razvetvleniia i Obryva Tsepei pri Tsepochechno-Teplovom Rasprostranenii Plameni. L. A. Lovachev. *AN SSSR Dokl.*, Nov. 21, 1958, pp. 501–504. In Russian. Determination of the effect of branching and discontinuity of chains in the case of thermal chain propagation of flames.

Heat Transfer

A Heat Conduction Problem Involving a Specified Moving Boundary. R. E. Gibson. *Quart. Appl. Math.*, Jan., 1959, pp. 426–430. Analysis of one-dimensional heat problems presenting exact solutions for two cases: when the rate of movement of the boundary is proportional to $t^{-1/2}$, and when t (time) is constant.

Teplovaia Konvektsiia vo Vrashchaiushcheisia Krugloi Trube pri Postoiannom Temperaturnom Gradiente (Szhimaemaia Zhidkost'). V. N. Golubenkov. *Prikl. Mat. i Mekh.*, Nov.-Dec., 1958, pp. 840, 841. In Russian. Study of the heat convection in a rotating infinite circular tube for the case of constant temperature gradient.

Analysis of Heat-Driven Oscillations of Gas Flows. V—Influence of Heat Transfer in the Burner Ports on the Stability of Combustion of Premixed Gases. H. J. Merk. *Appl. Sci. Res., Sect. A*, No. 1, 1958, pp. 1–27.

Effect of Spin on Natural Convection in Mercury Heated from Below. David Dropkin and Samuel Globe. *J. Appl. Phys.*, Jan., 1959, pp. 84–89. USAF-supported experimental investigation showing that, in the absence of spin, natural convection between two horizontal surfaces in mercury heated from below is given by the formula $N = 0.051R^{1/3}$ where N is the Nusselt Number and R the Rayleigh Number. Spinning the mercury about a vertical axis reduces the amount of convection after a certain value of the spin is exceeded.

VTOL & STOL

VTOL and STOL Research and Development in the Department of Defense. C. F. Horton and J. L. Klingenhagen. *AHS J.*, Jan., 1959, pp. 2–11. Development of relationships for the relative importance of VTOL and STOL to various missions and the applicability of the different types of VTOL and STOL.

Matching the Aircraft to the Job. R. S. Ross *AHS J.*, Jan., 1959, pp. 49–52. Description of the Convoplane or buried rotor system, capable of hovering and high-speed forward flight.

Some Thoughts on VTOL Propulsion. P. G. Kappus. *AHS J.*, Jan., 1959, pp. 43–48. Discussion of design and operational requirements for VTOL power plants.

The Future VTOL Transport. R. L. Lichten. *AHS J.*, Jan., 1959, pp. 39–42. Discussion of design and operational requirements for a transport aircraft and of the major advantages and disadvantages of the Bell XV-3 tilting rotor, fixed-wing aircraft.

Hovering and Low Speed Controllability of VTOL Aircraft. A. D. Crim. *AHS J.*, Jan., 1959, pp. 26–28. Comparison of the hovering and low-speed controllability of a number of existing and proposed VTOL test beds. The principal basis of comparison is angular acceleration and velocity capability in pitch, roll, and yaw.

Flight Testing Experiments with the Tilt-Wing Aircraft. W. Z. Stepniewski and P. J. Dancik. *IAS 27th Annual Meeting, New York, Jan. 26–29, 1959, Rep. 59-8.* 16 pp. Members, $0.50; nonmembers, $1.00. (Also in *Aero/Space Engrg.*, Feb., 1959, pp. 43–49.)

Design Considerations for a Propeller-Driven VTOL. D. W. Robinson, Jr. *AHS J.*, Jan., 1959, pp. 34–38. Description of the Kaman K-16B tilt-wing amphibian.

Force-Test Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. W. A. Newsom, Jr., and L. P. Tosti. *U.S., NASA Memo. 11-3-58L*, Jan., 1959. 53 pp. Measurement of both longitudinal and lateral stability and control characteristics in both the normal forward flight and the transition ranges.

Tilt Wing Propelloplane Potentialities. Joseph Stuart, III. *AHS J.*, Jan., 1959, pp. 29–33. Description of the Hiller X-18 propeller lifted, tilt wing aircraft and its current development status. Some possible single and tandem tilt wing designs are described.

The Tilt-Wing Propeller VTOL Aircraft—Present Status and Future Role. Joseph Mallen and Paul Dancik. *AHS J.*, Jan., 1959, pp. 15–19.

The Ducted Fan in VTOL Aircraft Design. N. E. Nelson. *AHS J.*, Jan., 1959, pp. 53–56. Discussion of the test programs, model design, wind tunnel programs, and construction of a full-sized aircraft, the Doak 16 (VZ-4DA).

Jet Lift VTOL. J. A. O'Malley, Jr. *AHS J.*, Jan., 1959, pp. 20–25. 11 refs. Summary of experience accumulated by Bell Aircraft in the design studies and flight tests of jet-propelled VTOL aircraft.

Water-Based Aircraft

A Theoretical and Experimental Study of Planing Surfaces Including Effects of Cross Section and Plan Form. Ch. L. Shuford, Jr. *U.S., NACA Rep. 1355*, 1958. 46 pp. 36 refs. Supt. of Doc., Wash., $0.45. Discussion of pure-planing theory for rectangular flat plates and V-bottom surfaces.

Corporate Member News

(*IAS News, Continued from page 27*)

• **Aerojet-General Corp.** has appointed J. B. Cowen to the new post of Manager of Administration of its Solid Rocket Plant; Ernest Leist has been named to head up field activities on the Navy Polaris fleet ballistic missile at Cape Canaveral Missile Test Center; Howard P. Mason has been appointed Corporate Base Manager for the Pacific Missile Range. Announcement of the establishment of an Anti-Submarine Warfare Division has also been made. . . .Ordnance Engineering Division at Frederick, Md., has been renamed the Atlantic Division because of the expansion of its activities.

• **Allis-Chalmers Manufacturing Co.** elected Joel Hunter a member of the Board of Directors, and Beauchamp E. Smith, General Manager of the Hydraulic Division, a Vice-President.

• **American Airlines, Inc.,** has elected Marshall D. Kochman as Vice-President–Properties and Facilities, and Alfred J. Moccia as Assistant Vice-President–Tax Administration.

• **Beech Aircraft Corp.** has named James N. Lew, Vice-President—Contract Administrator, to head all military activities.

• **Bendix Aviation Corp.** . . . Bendix Radio Division has promoted George W. Church to Assistant Manager, Aviation Products, and E. D. Hart to Engineering Manager, replacing Mr. Church. The German scientist Hans von Schultz, it was announced, has joined the Advanced Development Staff. . . . Friez Instrument Division has named John W. Hammond to the post of Assistant Director of Engineering, and Russell B. Stevenson as General Sales Manager. . . . Bendix-Pacific Division has appointed John R. Harkness to the new position of Electronics Manager.

• **Chance Vought Aircraft, Inc.,** announced the formation of a Range Systems Division under the direction of S. O. Perry, former Chief Engineer, Missiles.

• **Delco-Remy Division,** General Motors Corp., has appointed Vice-Admiral Truman J. Hedding, USN (Ret.) as Technical Assistant to the General Manager, with executive responsibility for defense programs.

• **Douglas Aircraft Co., Inc.,** has created the post of Director of Advanced Engineering Planning, and has appointed Carlos C. Wood, former Chief Engineer, Long Beach Division, to fill the new position.

• **General Electric Co.** . . . Defense Electronics Division's Missile and Space Vehicle Department has organized a new unit for Instrumentation and Communications which is headed by Richard E. Roberts.

• **Lockheed Aircraft Corp.** . . . Georgia Division has appointed W. A. Pulver, Chief Engineer for the past year, as Assistant General Manager. Arthur E. Flock, Chief Advanced Systems Research Engineer, California Division, has been made Chief Engineer, replacing Mr. Pulver. Four other promotions were made: Al W. Mooney was promoted to Project Manager of the newly created Engineering Department for the Mexican project; F. A. Matthews has been named Reliability Manager in the newly established Reliability Branch; V. E. Alexander has been promoted to Special Project Engineer. . . .Lockheed Missiles and Space Division is the new name of the former Missile Systems Division. Carl E. Johnson has been named Executive Assistant to Willis M. Hawkins, Assistant General Manager.

• **Minneapolis-Honeywell Regulator Co.** . . . Aeronautical Division has promoted Norman H. Holt to the position of Reliability Coordinator.

• **Pesco Products Division,** Borg-Warner Corp., has named Tom G. Conway Vice-President in Charge of Manufacturing.

• **Republic Aviation Corp.** has appointed Harley S. Jones, former Air Force aircraft and missile production planner, as Executive Vice-President.

• **Ryan Aeronautical Co.** has announced that Rear Adm. Eddie R. Sanders, USN (Ret.), has joined the Electronics Division as Executive Advisor to Owen Olds, Director of Engineering and Customer Relations, on matters pertaining to military relations.

• **Simmonds Aerocessories, Inc.,** has named Harrison F. Edwards to the new position of Chief Engineer, Product Engineering, at its manufacturing division in Vergennes, Vt.

• **Solar Aircraft Co.** . . . Des Moines Division has named Raymond T. Zwack as Manager of Development Engineering.

• **Space Technology Laboratories, Inc.,** has elected Dr. George E. Mueller and Dr. Edward B. Doll as Vice-Presidents. Dr. Mueller will continue to serve as the Director of the Electronics Laboratory. Dr. Doll will assume new responsibilities as Associate Director of the Systems Engineering Division. He will also continue to serve as Program Director for the USAF's Atlas.

• **Thompson Ramo Wooldridge Inc.** has elected Eben H. Jones as Vice-President and General Counsel. Four operating executives also made Vice-Presidents are: Pierce T. Angell, Engineering Manager, Tapco Group; Robert E. Cummings, Manager, Thompson Products Valve Division; William M. Jones, Manager, Thompson Products Commercial Electronics Group, and Carl L. Kahlert, Manager, Thompson Products Replacement Division. In addition, James R. Lewis has been appointed to the new corporate staff position of Director of Public Relations.

• **Vertrol Aircraft Corp.** has appointed Friedrich L. von Doblhoff as Director of Engineering—International Division.

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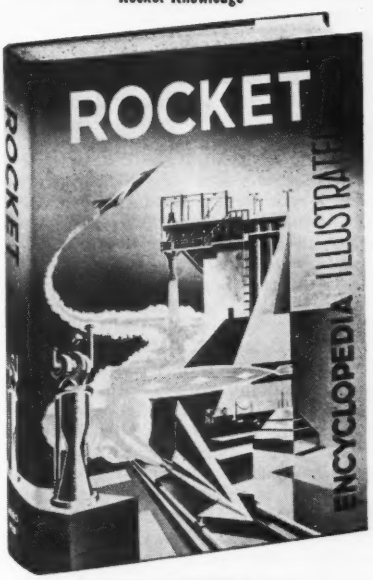

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Channel Cities Subsection

Missile and Space Challenge Subject of L. Eugene Root

A review of the problems encountered in the development of the Polaris IRBM and Discoverer satellite vehicle was presented by **L. Eugene Root,** Vice-President and General Manager, Lockheed Missiles and Space Division, Lockheed Aircraft Corp., in his talk on **"Stepping Up to the Missile Space Business"** at the new subsection's first dinner meeting on January 13.

Mr. Root said that the major problems in most cases were without precedence for a solution, and represented a real challenge to the ingenuity of those engaged in the programs. He reminded all scientists and engineers associated with the missile business of their responsibilities to face up to these technical challenges, so the U.S. space program would move forward faster.

John Northrop, Aeronautical Consultant, was Guest Chairman and introduced Mr. Root.

The Chairman of this new subsection is Dr. A. B. Focke, Technical Director of the Pacific Missile Range; other *protem* officers are Dr. Adam Zahorski, Zahorski Engineering, Inc., Vice-Chairman, and Herbert J. Spey, Pacific Missile Range, Secretary-Treasurer.

HERBERT J. SPEY
Secretary-Treasurer

Chicago Section

Dr. Victory Outlines Objectives in Space

The objectives of aeronautical and space activities stated in the National Aeronautics and Space Act of 1958 were outlined by **Dr. John F. Victory,** Assistant to the Administrator, NASA, in his talk on **"The NASA and Space Technology"** at a January meeting. Dr. Victory said that the 1958 Act declares "it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind." He cited U.S. resources, knowledge, will, and responsibility as reasons why we should pioneer in the space age and said that reliable rocket boosters would determine our ability to progress in space exploration. He noted that the 1,500,000 lb. thrust rocket engine was about 4 years away; then, he said, will come chemical rockets with thrusts of several million lbs. Nuclear propulsion will increase thrust more, and ion or plasm propulsion will permit space exploration.

Dr. Victory spoke briefly on the NASA directed national effort "Project Mercury" which has as its objective the putting of man into space. The Army Jupiter missile is the most likely vehicle for this venture, he said. Success is several years away, with problems of man and machine yet to be solved. Dr. Victory conceded that the Russians were ahead in the space race and mainly blamed our archaic educational system which does not produce thinkers.

J. S. ISLINGER
Vice-Chairman

Hampton Roads Section

Classified Talk by Col. Tosti

"Air Force Research and Development in the Space Age" was the subject of a classified talk given by **Col. Carlo R. Tosti,** USAF, at a January meeting. Colonel Tosti, Special Assistant to the Commander, ARDC, gave a graphic two hour talk on the current status of Air Force research and the research plans in the near future. The talk was well documented with films and slides.

JOHN M. EGGLESTON
Secretary

Los Angeles Section

Specialist, Dinner Meetings Highlight Activities

Two methods for limiting the peak deceleration of space vehicles during reentry were described at a January Specialist Meeting by **F. W. Hartwig,** Space Technology Laboratories, in a paper coauthored with **C. B. Cohen,** STL, and **Prof. Lester Lees,** California Institute of Technology. It was found that by the use of a continuous drag modulation the deceleration loads could be reduced by as much as 50 per cent without affecting significantly the total aerodynamic heating.

In the second method, aerodynamic lift was employed during entry into the earth's atmosphere at either orbital or escape velocity. The range of allowable entry angles for a prescribed peak deceleration was greatly increased while the total heat energy was held to about the same as for nonlifting vehicle.

▶ **"Flight Testing—Yesterday, Today, and Tomorrow"** was compared at a January Dinner Meeting by **Brig. Gen. Marcus F. Cooper,** Commander, Air Force Flight Test Center, EAFB. Describing the role of the test pilot in the development of military aircraft, he noted his change in duties from those of crew chief-mechanic-engineer prior to World War II to test director at the present time. Despite the increase in complexity of projected aircraft missiles, Gen. Cooper predicted that the test pilot, though perhaps in a modified role, will continue to be essential.

▶ A method of optimizing the staging of multistage boost vehicles was outlined at another January Specialist Meeting by **Carl H. Builder,** Astro Division, Marquardt Aircraft Co. Noting that minimum gross weight is not likely to be the only criterion of interest and that a large number of parameters, such as cost, empty weight, volume, etc., are approximately proportioned to stage weight over the range of interest, Mr. Builder presented a means of optimizing staging for many criteria of interest, including the criterion of minimum gross weight.

HERBERT R. SAFFELL, JR.
Secretary

San Antonio Section

Space Exploration Highlights January, December Meetings

Major W. R. Aiken, Education Planning Chief of the Officers Candidate School at Lackland AFB, spoke at the January meeting on **"Einstein and Space Exploration."** He approached the subject from the possibility of an "outer" space visitor and tied this in with his experiences on the Air Force's "Unidentified Flying Object" project. Major Aiken gave the relative distances between the galaxies and planets, and discussed in detail Einstein's "special", "general" and "unified" theories. He feels that in the universe there are at least 100,000 earths that support human life, and further persisted that the speed of light is not ultimate.

Chairman Cecil Barnes formally notified members present of the death of one of our founder members, Gen. Clement McMullen (Ret.). In honor of General McMullen, it was announced that the Section would make a donation to Boysville, a boys' home in San Antonio.

ROBERT R. PERRY
Secretary

Master Sergeant Robert R. Perry, Chief of Technical Training for Headquarters 3510th Maintenance and Supply Group at Randolph AFB and Secretary of the San Antonio Section, presents a paper on "Inside the Vanguard Vehicle and Its Satellite" at the December meeting. Others, *left to right,* are Mrs. Cecil Barnes; Rev. Father Buehler, President of St. Mary's University; Cecil Barnes, Section Chairman; and Jean Perry, wife of the guest speaker and a graduate Aircraft Performance Engineer.

▸ The December meeting, commemorating the 55th anniversary of the Wright brothers' flight, was held at Billy's Restaurant, near the Kelly Air Force Base.

Guest speaker **Master Sergeant Robert R. Perry,** Chief of Technical Training for Headquarters 3510TH Maintenance and Supply Group at Randolph AFB, spoke on **"Inside the Vanguard Vehicle and Its Satellite."** He dealt with the intricacies and the vast problems that are encountered by our present day "missilemen"—not only regarding the satellite launching vehicle, but also in relation to the problems of designing and placing a man-made object into orbit about the earth (see photo, p. 136).

To clarify his presentation, Sergeant Perry used excellent color coded scale models of the Vanguard vehicle and its 21 lb. satellite. Each guest was provided with schematic drawings of the missile and satellite, coded and marked as to match the actual models, to provide a means of following the presentation.

CECIL W. BARNES
Chairman

Seattle Section

Edward C. Wells Looks Into the Future

That an understanding of the past can be of invaluable assistance in charting a course for the future was one of the thoughts emphasized by **Edward C. Wells** in his talk entitled **"Fifty-five Years After the Wright Brothers—A Look Into the Future,"** at the January 14 Dinner Meeting. Mr. Wells, President of the IAS for 1958, is Vice-President of Boeing Airplane Co., in charge of the Systems Management Office.

Noting the giant strides that have been made since the time of the Wright brothers to the advent of the era of the jet transport of today, the roles of both turbojet and the turboprop airplanes were briefly outlined in relation to the need of the air transport industry and the traveling public. Mr. Wells then remarked on the possibilities for the next logical step in air transport development—the supersonic transport. The importance of the long-term, well-established trend for the economical range of an airplane to increase with speed was stressed in relation to the flexibility of such an airplane over airline routes, and in its ability to fill a genuine need. In this respect, the necessity for parallel developments in transportation was emphasized in order that the full potential of the supersonic transport might be realized.

Mr. Wells compared the dawning of the space age, with its seemingly limitless possibilities, to the sudden availability of a limitless candy store, with the attending possibilities and even likelihood of a severe case of indigestion as the price of overindulgence. As we follow the historical cycle of gaining knowledge, giving it concrete form, and exploiting these forms to the fullest in the space age as we have in the past in aviation, man is likely to find that the final limits to this process are his capacity for gaining and using new knowledge and the resources at his command, both human and material. Even if the trend predicted by Dr. E. Teller, which envisions a doubling of human knowledge every 100 years, materializes, the problems of managing an enterprise which utilizes the knowledge and skills of an ever increasing number of more and more highly specialized individuals would seem eventually to constitute another limit to man's exploitation of space. The many problems which are to be overcome are such as to assure that this task will be long and arduous. Nevertheless, Mr. Wells indicated, each of us should be willing to play our individual parts to the fullest in this gigantic undertaking, and to resist any temptation to rest upon the laurels of our past accomplishments.

Finally, Mr. Wells expressed his gratification for being able to work with the IAS, particularly in an active year which saw such important events as the inauguration of a series of international conferences in the aeronautical and space sciences at Madrid.

Over 250 members and guests attended this meeting, held at the Seattle Tennis Club.

LOUIS B. GRATZER
Secretary

Dr. Igor I. Sikorsky *(right)*, guest speaker at the inaugural banquet of the new South Florida Section, is shown with Program Chairman E. L. Eveleth.

South Florida Section

Sikorsky Is Speaker at Inaugural Banquet

Dr. Igor I. Sikorsky, Consulting Engineer, Sikorsky Aircraft, spoke on **"Transport and Cargo Crane Helicopters"** at the inaugural banquet at Bahia Mar Yacht Club, Fort Lauderdale, Fla., early in January.

Dr. Sikorsky told the 110 members and guests of future potential of the new S-62 helicopter for rescue purposes. The crane-type helicopter is able to lift several thousand lbs. to inaccessible areas. He said that the "cranes" have been used successfully by the petroleum, natural gas, and telephone industries.

E. L. Eveleth, Vice-President and General Manager of Southeast Machinery Co., was Program Chairman of the event.

ANDREW C. MCDERMOTT
Secretary

Tullahoma Section

Research, Development Discussed

At the January meeting, an informal talk was given by **Julius Lukasiewicz,** Chief of the Gas Dynamic Facility, Air Engineering Development Command, on **"Research and Development in the United Kingdom, Canada, and the United States."**

Mr. Lukasiewicz posed and discussed the following questions in his talk: What are the administrative restrictions on research and development in various countries? What division do the various countries make between applied and basic research? With the multibillion dollar cost now associated with weapon systems, what contribution can an economically small country such as Canada make in the research and development field?

He also discussed the future role of helicopters and VTOL aircraft in the industrial development of Canada's remote northern territories. A scenic movie was shown describing the operations of the modern-day helicopter "bush" pilot when, as in some cases, a 14 by 14 ft. wooden platform perched on a mountain peak is the only landing area.

MILTON W. DAVIS
Secretary

Tulsa Section

DC-8 Fuselage Structure

Russell W. Brown, Chief of the Structures Design Section, Douglas Aircraft Co., Inc., Tulsa Division, spoke on **"Fatigue Test and Evaluation of the DC-8 Fuselage Structure"** at the December meeting.

Results of an underwater fatigue and fail-safe test program of the DC-8 fuselage were presented. Data from this program has been especially useful in evaluating and organizing inspection procedures for high-altitude jet transport airplanes. An equivalent of 40 to 120 years of endurance under simulated service loads was imposed on the specimen. Damage propagation rates and fail-safe characteristics of the structure were studied under these deliberately prolonged exposures of fatigue which were beyond the scope of experience permissible in actual service. The purpose was to present the actual data taken from this test. The presentation included crack rates and maximum crack lengths attained. It also included a discussion of the critical locations in which these cracks occurred and the improvements incorporated in production of DC-8 airplanes as a result of these tests. This information was the subject of a paper presented at the Eleventh Technical Conference of International Air Transport Assembly at Monte Carlo, in September, by the Chief Engineer of Douglas Aircraft, Santa Monica Division.

ALLAN M. MCCASKILL
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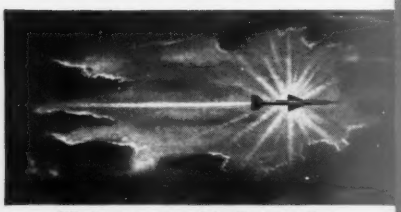

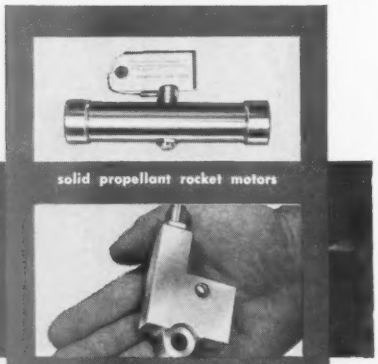

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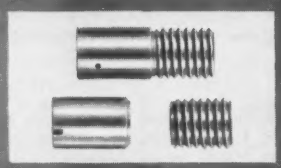

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Washington Section

Gen. Orval Cook is Speaker at January Meeting

General Orval R. Cook, President, Aircraft Industries Association of America, addressed the January meeting on **"The Engineer and Management."** Thomas Meloy, President of Melpar, Inc., was the Honorary Chairman for the meeting. Douglas Aircraft sponsored the social period with Frank Duquette representing Douglas as host for this portion of the program. S. Paul Johnston, Director of the IAS, was guest for the evening.

Mr. Meloy, whose company employs 1,500 engineers, physicists, mathematicians, and chemists, out of a total of 5,000 employees, set the stage with some observations on engineers and management. In his opinion, good managers basically require a natural ability. After selecting a man with management ability, he can be taught techniques which will improve his capacity, but training is not enough to make a good manager. A manager needs to know accounting, business law, corporate structure, and be able to express himself well. He must also be able to select well from the proposals and people that come to him. In today's technological advances, the inventive genius sitting alone in a room has disappeared and has been replaced by group effort. Consequently, the engineer has to participate more and more in management. After his remarks, Mr. Meloy introduced General Cook.

General Cook reviewed the technical achievements of the United States and Russia during the past year. He stated that the most dramatic object in space today was the Russian "Lunik" or "Mechta," just as the "Sputnik" was the earth's most dramatic fellow traveler a year ago. This, however, is not a clear indication that we have made little or no progress in the year, as it might appear to be.

We have made clearly identified progress. We have a national sense of urgency. We have a national declaration of intent that the conquest of space is vital to our welfare and security. We have created an organizational structure to carry out that intent. We have established requirements and placed hardware orders for some very advanced systems. However, the "Lunik" is evidence that we have not been able to catch up to the Russians within a year. We are on the move, but we must not expect the programs initiated during the year to bear fruit in that year or even the following year. Our technical achievements in 1958 were the result of work started several years earlier.

General Cook then stated, "How much more effective our efforts might have been if we had planned them can be left to your imagination and judgement." More than ever before, advance planning is the critical element in formulating management decisions, whether on the national or corporate level. The rate of our technological advances is of a revolutionary nature. Almost overnight, weapon availability has reached a point where it precedes

(*Continued on page 143*)

REVIEWS OF Books

. . . in the field of aeronautical engineering and space technology

ACOUSTICS, SOUND, NOISE

Introduction to a Study of Mechanical Vibration. G. W. Van Santen. 2nd Rev. Ed. New York, The Macmillan Co., 1958. 310 pp., illus., diagrs., tables. $8.50.

The object here is to review the elementary theory of mechanical vibrations, as well as some of the more important problems of vibration encountered in practice. The revision includes corrections of the 1953 edition, references to the latest technical advances, and more detailed information on some modern vibration measuring instruments.

AEROELASTICITY

Proceedings of the National Specialists Meeting on Dynamics and Aeroelasticity (Unclassified Portions), Fort Worth, Texas, November 6-7, 1958. Sponsored by the Institute of the Aeronautical Sciences in Cooperation With the Texas Section of the IAS. New York, IAS, 1958. 135 pp., illus., diagrs., tables. $6.00.

Contents: Some Recent Developments in the Flutter Analysis of Low-Aspect-Ratio Wings, Pao-Tan Hsu. Developments in the Flutter Analysis of General Plan Form Wings Using Unsteady Air Forces from the Kernel Function Procedure, H. J. Cunningham and D. S. Woolston. Investigation of a Method for the Measurement of Subsonic Oscillatory Aerodynamic Influence Coefficients, H. N. Abramson. An Elementary Explanation of the Flutter Mechanism, S. Pines. A Philosophy of Design for Flutter, A. L. Head, Jr. The Use of Low Speed Flutter Model Tests and Trend Curves to Establish Flutter Boundaries, P. T. Mahaffey. A Method of Normal Mode Excitation Utilizing Admittance Measurements, G. W. Asher. Vibration Analysis of Orthogonally Stiffened Circular Fuselage and Comparison with Experiment, H. C. Nelson, B. Zapotowski, and M. Bernstein. A Stiffness Matrix Method of Natural Mode Analysis, J. S. Archer. Landing Gear Vibrations Induced by Skidding Tires—Theoretical and Experimental Study, N. H. Zimmerman. Some Studies of the Dynamic Motions of Hypervelocity, High Altitude Vehicles, E. L. Kistler, Jr., and F. F. Capalongan. The Influence of Rate of Change of Altitude and Acceleration on the Longitudinal Dynamic Stability of Aircraft and Missiles, V. K. Merrick. Dynamic Model Tests of an Unconventional Landing Configuration, J. N. Deutschmann and M. Schlessinger.

AERONAUTICS, GENERAL

Research and Development; Program and Progress Report, 14 August 1957–31 October, 1958. U.S. Federal Aviation Agency. Washington, Superintendent of Documents, 1958. 124 pp., illus., diagrs. $0.70.

This report is a summary of the programs established and the progress made on carrying out the modernization of the national system of air traffic control and air navigation. It covers the research and development activity of the Airways Modernization Board since its establishment by Congress on August 14, 1957. The functions of this Board were transferred to the Federal Aviation Agency on this date, as authorized by the Federal Aviation Act of 1958.

Contents: Executive Order Transferring AMB to FAA. Organization Chart, Bureau of Research and Development. Research and Development Progress Summary. Summary of Significant Active Contracts. Funds. Personnel. The Common System Time Schedule. Research and Development Program Documentation. Current Projects and Task Activity. Summary of Active Projects and Tasks. Operations Analysis Functional Responsibilities. Operations Analysis Program Descriptions. Systems Analysis Functional Responsibilities. Systems Analysis Program Descriptions. Systems Experimentation Functional Responsibilities. Systems Experimentation Program Descriptions. Development Functional Responsibilities. Development Program Descriptions. Appendix.

ASTRONOMY

Physics of Meteor Flight in the Atmosphere. Ernest J. Öpik. (*Interscience Tracts on Physics and Astronomy, No. 6.*) New York, Interscience Publishers, Inc., 1958. 174 pp., diagrs., tables. $1.95.

The booklet has originated from a series of lectures on "The Physics of Meteors and their Cosmic Relationships," delivered in the spring term of 1957 at the Department of Physics of the University of Maryland, during the author's stay there as Visiting Professor. The present scope is somewhat narrower and covers chiefly the phenomena occurring during the flight of the meteor through the terrestrial atmosphere. The various chapters deal with: the atmosphere, the classification and physico-chemical properties of meteors, meteoroid energy transfer, ablation, details of energy transfer and types of ablation, atomic collisions, and meteor radiation.

The author is Director of the Armagh Observatory, Armagh, Northern Ireland.

CONTROL THEORY

Handbook of Automation, Computation, and Control. Vol. 1, Control Fundamentals. Edited by Eugene M. Grabbe, Simon Ramo, and Dean E. Wooldridge. New York, John Wiley & Sons, Inc. 985 pp., diagrs., tables. $17.

This *Handbook* is a three volume set directed toward all levels of technical personnel who are concerned with the application of technology to the developments in automatic equipment and systems and contains a compilation of available theory and information on general mathematics, feedback control, computers, data processing, and systems design. The various sections were written by specialists in the field of control theory who have laid particular emphasis on practical methods of applying theory, on new techniques and components, and on the ever broadening role of the electronic computer. Each chapter begins with definitions and descriptions aimed at providing perspective and then moves on to more complicated theory, analysis, and applications. In general, the *Handbook* assumes some engineering training and will serve as an information source and refresher for practicing engineers; for management, it will provide a frame of reference and background material for understanding modern techniques of importance to business and industry.

Volume 1 contains a strong treatment of general mathematics which includes chapters on subjects not ordinarily found in engineering handbooks. These include sets and relations, Boolean algebra, probability, and statistics. Additional chapters are devoted to numerical analysis, operations research, and information theory. Finally, the present status of feedback control theory is summarized in eight chapters. *Volumes 2* and *3*, which are not yet available for distribution, will deal with computers and data processing and systems and components, respectively.

Contents: (1) Sets and Relations, R. M. Thrall. (2) Algebraic Equations, R. C. Lyndon. (3) Matrix Theory, R. C. Lyndon. (4) Finite Difference Equations, G. E. Hay. (5) Differential Equations, G. E. Hay and W. Kaplan. (6) Integral Equations, E. H. Rothe. (7) Complex Variables, W. Kaplan. (8) Operational Mathematics, W. Kaplan. (9) Laplace Transforms, W. Kaplan. (10) Comformal Mapping, W. Kaplan. (11) Boolean Algebra, A. H. Copeland, Sr. (12) Probability, A. H. Copeland, Sr. (13) Statistics, A. B. Clarke. (14) Numerical Analysis, B. Dimsdale and others. (15) Operations Research, E. L. Arnoff. (16) Information Theory, P. Elias. (17) Smoothing and Filtering, P. Mertz. (18) Data Transmission, P. Mertz. (19) Methodology of Feedback Control, W. M. Gaines. (20) Fundamentals of System Analysis, S. J. Jennings and A. A. Winkeljohann. (21) Stability, W. E. Sollecito and S. G. Reque. (22) Relation between Transient and Frequency Response, C. E. Bradford and M. W. DeMerit. (23) Feedback System Compensation. P. G. Cushman. (24) Noise, Random Inputs, and Extraneous Signals, D. L. Lippitt. (25) Nonlinear Systems, W. M. Gaines. (26) Sampled-Data Systems and Periodic Controllers, J. E. Barnes, Jr.

DIRECTORIES

The Aerospace Industry; A Report on Plants and Facilities. Prepared by AERO/SPACE ENGINEERING; Compiled by Hugh C. Judge. 3rd Ed. New York, IAS, 1958. 32 pp. $0.50.

A compilation of the plants and facilities in the United States engaged in the research, design, or manufacture of airframes and propulsion units for aircraft, missiles, rockets, and outer space vehicles. Also included is a representative list of the manufacturers of complete systems for air and space vehicles.

Whites Air Directory and Who's Who in New Zealand Aviation (Including the South Pacific), Vol. 10, 1958–59. Auckland, N.Z., Whites Aviation Ltd., 1958. 152 pp. $1.50.

Contents: Historical Events; Who's Who Section; Former Chiefs of Staff, R.N.Z.A.F.; Royal New Zealand Air Force; Civil Aviation Administration; Air Services Licensing Authority; Scheduled Airlines; Airline Representatives; Non-Scheduled Operators; Aerial Work Operators; Maintenance & Overhaul Companies; Aerial Photography; Approved Firms; Aerodromes and Airfields; Meterological Information; Radio Facilities; Air Traffic Control; Aeronautical Publications; Aeronautical Training; Societies and Clubs; Aero Clubs; Gliding Clubs; Gliding Records; Air Pageant Trophies; Scholarships and Awards; Registered Aircraft; Licence Holders; Aircraft Maintenance Engineers; Aircraft and Engine Representatives; Components and Materials; Airways Booking Agents; Air Freight; Customs Agents; Insurance Companies and Brokers; Aviation Fuel and Oil; Model Aircraft Supplies; General Index; Index to Advertisers.

DOCUMENTATION

Information Storage and Retrieval, Theory, Systems, and Devices. Edited by Mortimer Taube and Harold Wooster. (*Columbia University Studies in Library Service, No. 58-190.*) (*AFOSR TN 10.*) New York, Columbia University Press, 1958. 228 pp., diagrs. $6.00.

This book is the result of a Symposium on Information Storage and Retrieval, Theory, Systems, and Devices held in Washington, D.C., March 17, 18, 1958.

Contents: Part I. Working Papers, by Mortimer Taube: The Scope and Limits of the Problem; Historical Solutions; The Present State of Theory, with an Addendum on Indexing, Language and Meaning; The Present State of Devices and Systems; Future Research in Theory; Future Development of Devices and Systems.

Part II. Discussion: The Relation of Storage to Retrieval, A. Kreithen; The Relation of Physical to Symbolic Systems, R. Shaw; The Logic of Retrieval Devices, M. Taube; Digital Coding for Information Retrieval, C. N. Mooers; The Grouping and Arrangement of Terms, Items, and Their Codes, E. Wall; The Environment and the Requirements of a System, C. Bernier; Indexing, Language, and Meaning, H. P. Luhn.

EQUIPMENT

Electricity in Aircraft. F. G. Spreadbury. New York, The Macmillan Co., 1958. 342 pp., illus., diagrs. $8.00.

Since 1945 the number of electrical applications in aircraft has increased greatly and, consequently, so has the power demand on the generating system. This book, which is intended for electrical engineers, technicians, and ground service crew specializing in all aspects of aircraft electricity, deals mainly with aircraft electrical equipment that has come into use since that date. Electrical ignition, becoming of diminishing importance in aircraft, is treated only with regard to its application to turbine starting.

Contents: (1) Systems of Generation in Aircraft: Direct Current. (2) Systems of Generation: Alternating Current and Rectified A. C. (3) Rotary Converters and Inverters. (4) Aircraft Storage Batteries. (5) Switchgear and Cables. (6) Motors and their Applications. (7) General Utilization Equipment in Aircraft. (8) Testing and Test Equipment. Index.

FUELS

Rocket Propellants. Francis A. Warren. New York, Reinhold Publishing Corp., 1958. 218 pp., illus., diagrs., tables. $6.50.

The purpose of this book is to provide technical men with basic information on the materials being used to propel rockets and missiles. In addition to detailing the history of rocket fuel development, the various chapters deal with: the composition, manufacturing methods, and performance details of both solid- and liquid-propellants used in rockets, from small signal

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The author is Manager of the Special Projects Section, Department of Chemical Research, Southwest Research Institute.

The Storage and Handling of Jet Fuels at Airports. Division of Marketing, Aviation Technical Service Committee, American Petroleum Institute. 3rd Ed. (*API Bulletin 1503.*) New York, API, Jan., 1958. 11 pp., diagrs. $0.50.

MATERIALS

Laminated Plastics, Including High-Pressure and Low-Pressure Types and Reinforced Plastics. D. J. Duffin and Charles Nerzig. (*Reinhold Plastics Applications Series.*) New York, Reinhold Publishing Corp., 1958. 254 pp., illus., diagrs., tables. $5.75.

Here is a thorough survey of the manufacturing, fabrication, and applications of high- and low-pressure laminates. Discussions deal with the various types and grades of raw materials and resins used; their physical characteristics; and includes numerous tables of mechanical, chemical, and electrical properties as related to various kinds of industrial and consumer applications. The appendix features a comprehensive list of plastics manufacturers and trade names.

The Theory of the Properties of Metals and Alloys. N. F. Mott and H. Jones. (Reprint of 1936 Edition.) New York, Dover Publications, Inc., 1958. 326 pp., diagrs., tables. $1.85.

MATHEMATICS

Numerical Analysis and Partial Differential Equations: Contemporary State of Numerical Analysis, George E. Forsythe; **Linear Partial Differential Equations,** Paul C. Rosenbloom. New York, John Wiley & Sons, Inc., 1958. 204 pp. $7.50.

The prime purpose of these two survey articles is to summarize the state of the fields which they cover, as determined by contributing developments at various times and in many places. Numerical analysis is viewed by G. E. Forsythe as a means of devising and evaluating numerical techniques for employing computers to solve problems, and to study their convergence and errors. The emphasis is on recent developments and the contributions made by Russian authors and others less known in the Western world. Confining the work to linear differential equations, P. C. Rosenbloom in his article deals primarily with advances in the field since 1953, with reference to older works providing essential background. Discussions center on methods that are applicable to wide classes of equations and for the most part results are stated in the form of definite theorems to facilitate reference work.

MECHANICS

Mechanics. Part 1, Statics. J. L. Meriam. 2nd Edition. New York, John Wiley & Sons, Inc., 1959. 393 pp., diagrs., tables. $5.00.

The emphasis in this book, which first appeared in 1951, is on engineering or applied mechanics, and it has been designed for the basic mechanics courses in the normal engineering curriculum. The treatment of fluid statics has been completely rewritten, and the topic is introduced from the three-dimensional aspect at the start to help clarify this problem and a new chapter on vector methods has been added so that the notation of vector algebra and vector calculus may be employed if desired. Approximately 50 per cent of the problems have been replaced with new problems patterned after design situations from a variety of engineering activities.

The Author is Professor of Engineering Mechanics, University of California.

MISSILES, ROCKETS

Rocketry and Space Exploration. Andrew G. Haley. Princeton, N.J., D. Van Nostrand Co., Inc., 1958. 334 pp., illus., diagrs. $6.75.

In this profusely illustrated contribution to astronautics literature, the incumbent President of the International Astronautical Federation ranges over a wide variety of efforts by famous men, separate nations, and international groups to harness the rocket for multifarious purposes and to begin the penetration of astronomical space. Mr. Haley has not overly concerned himself with subjects which have been by now very adequately covered in other works, but has chosen, through a careful screening of existing literature, to add to published information such points as may have escaped thorough scrutiny in the past. In keeping with this principle, he has included an English translation of Esnault-Pelterie's pioneer essay, *Considerations on the Results of Indefinite Decrease in Weight of Engines*, as an appendix to this book.

In general, *Rocketry and Space Exploration* does not pretend to undertake scientific discussions of deep import to specialists, but endeavors to tell the story of rocketry from its earliest begin-

nings through World War II, when present generations were introduced to the V-2, up to today's highly publicized launchings of missiles and artificial satellites. The operation of rockets is described in nontechnical terms and particular attention is paid to the industrial aspects of rocket and missile production in the United States as well as the achievements of Great Britain, the U.S.S.R., and other countries in this respect. In addition, the author traces the efforts toward international cooperation in astronautics and in other areas of knowledge which, by their nature, demand a free exchange of information on an international scale.

A particularly useful chapter in this book is the one entitled "The Working Societies" in which the names and publications of all known astronautical societies are listed and their objectives summarized. Similar information relating to the industry that, in most cases, designs and manufactures missiles and rockets and the military establishments that test them, is given in another chapter, "Rockets and Missiles—An Industry." The volume closes with Appendix 2, which is a facsimile of documents on astronautical communications studied by the International Radio Consultative Committee (CCIR) for the purpose of allocating frequency bands.

Guided Missile Engineering. Edited by Allen E. Puckett and Simon Ramo. New York, McGraw-Hill Book Co., Inc., 1959. 467 pp., illus., diagrs., tables. $10.

Intended as an inclusive introduction to guided missile engineering, this book contains important principles and engineering techniques of the various sciences that make up this field, and their interrelations as seen by eighteen missile engineering experts. The various chapters are directed at the engineer or scientist who may have considerable skill in some other area and a good general technical background, but little familiarity with the subject in question.

Contents: (1) The Guided Missile System and Its Components, R. P. Johnson. (2) Aerodynamics of Guided Missiles, A. E. Puckett. (3) Aerodynamic Stability and Control, W. M. Bleakney. (4) The Rocket Motor, M. C. Beebe, Jr. (5) Ramjets, L. Stoolman. (6) Information Theory and Missile Guidance, F. P. Adler. (7) Principles of Missile Navigation, J. M. Wuerth. (8) Random Phenomena and the Precision of Guidance and Control, R. H. Delano. (9) Servos and Feedback Control, R. K. Roney. (10) Instrumental Gyroscopy, G. A. Van Lear and H. A. Lassen. (11) Radio Propagation, B. F. Miller. (12) Microwaves, R. B. Muchmore. (13) Radar, R. S. Julian. (14) Analog Computers, R. H. Griest. (15) Digital Computers, E. C. Nelson. (16) Trajectory Analysis and Flight Simulators, R. R. Bennett. (17) The Integration of Design; Over-All System Considerations, J. C. Fletcher. Appendix: Derivation of Generic Drifts, H. A. Lassen. Index.

Fundamentals of Advanced Missiles. Richard B. Dow. New York, John Wiley & Sons, Inc., 1958. 567 pp., illus., diagrs., tables. $11.75.

This book emphasizes basic principles in science and engineering that are applicable to and prerequisites for estimating the performance of guided missiles, and space vehicles. It deals with their operational characteristics and the functions of component parts of missiles and weapon systems in general.

Applications of the basic principles are discussed from the point of view of theory, experimentation, and typical examples encountered in practice, rather than from the standpoint of detailed design of particular missile types. The nine chapters are devoted to discussions on: kinematics of flight, application of fluid mechanics to aerodynamics and propulsion, dynamics, applications of probability and statistics, properties of microwaves, infrared radiation, radar, guidance, and guided-missile systems.

Dr. Dow is now Aeronautical Research Administrator for AFOSR, ARDC, USAF, Washington, D.C.

PHYSICS

Introduction to the Physics of Many-Body Systems. D. Ter Haar. (*Interscience Tracts on Physics and Astronomy. No. 5.*) New York Interscience Publishers, Inc., 1958. 127 pp. $3.85.

An introduction to the field of many-body physics that stresses the main points and indicates the trend of recent developments. The first part of the book deals with: theories where one tries to reduce the problem to that of free particles, the self-consistent field method, the statistical theory of the atom, Breuckner's theory of the nucleus, and a discussion of holes, excitons, and polarons in solid-state physics. The second part deals with recent work on collective behavior theories, and applications of these theories to different fields.

PRODUCTION

Engineering Drawing. 2nd Ed. Frank Zozzora. New York, McGraw-Hill Book Co., Inc., 1958. 440 pp., diagrs., tables. $6.50.

This is a concise text on the fundamentals of engineering drawing, descriptive geometry, and graphical analysis, and is intended for the student. Published previously in 1953, the new edition has been expanded to include additional chapters on Structural Drawing, Charts and Graphs, Electrical Drafting, and Descriptive Geometry. The chapter on Freehand Drafting has been expanded, and several new constructions have been added to the chapter on Geometrical Constructions. The chapter on Dimensioning has been enlarged to include many new features, especially tolerance dimensioning for surfaces, geometrical form, and position. In addition, new sections on jigs and fixtures have been added to the chapter on Cams and Gears and many of the old illustrations have been redrawn and about 200 new ones added.

RESEARCH FACILITIES

Wind Tunnel Installations in the United States. Prepared by AERO/SPACE ENGINEERING. 3rd Ed. New York, IAS, 1959. 9 pp. (not for sale)

SPACE TRAVEL

Proceedings of the 8th International Astronautial Congress, Barcelona, 1957. Editor-in-Chief, F. Hecht. Vienna, Springer Verlag, 1958. 607 pp., illus., diagrs., tables. DM 125., $29.75

Contents: Essai de contribution à l'autopropulsion nucléaire (Contribution to the Problem of the Nuclear Rocket Engine), J.-J. Barré. Essai de contribution à la propulsion ionique (Contribution to the Ionic Propulsion), J.-J. Barré. Multi-Directional G-Protection in Space Vehicles, H. J. von Beckh. Über die Strömung von Zweiphasengemischen (On the Flow of Two-Phase Mixtures), H. Bednarczyk. The Weight of Minimum Cost Orbital Ferry Vehicles, B. Bergqvist. "Biospheric Index", a Contribution to the Problem of Determination of the Existence of Extra-Solar Planetary Biospheres, Th. P. Bûn and F. A. Pereira. Previsione tempestiva delle caratteristiche del moto di mobili aero-balistici nella cibernetica aeronautica (Well-Timed Foresight of the Characteristics of the Motion of Aeroballistic Missiles in Aeronautical Cybernetics), C. E. Cremona. Research Goals in Astronautics, W. O. Davis. Instrumented Comets—Astronautics of Solar and Planetary Probes, K. A. Ehricke. Die Sternenökosphären im Radius von 17 Lichtjahren um die Sonne (The Star Ecospheres within a Radius of 17 Light-Years around the Sun), J. Gadomski. Recovery of a Circum-Lunar Instrument Carrier, C. Gazley, Jr., and D. J. Masson. On the Generation of Temperatures to 30,000° K., P. E. Glaser. A Method of Integrating the Equations of Motion of a Body Entering an Arbitrary Atmosphere with an Automatic Error Analysis, F. G. Gravalos. Pilotage d'un astronef par des moyens radioélectriques (The Navigation of a Space Vehicle by Means of Radio-Electric Methods), H. Gutton. Space Law—The Development of Jurisdictional Concepts, A. G. Haley. Über Stabilitätsuntersuchungen an flüssigkeitsgetriebenen Raketenmotoren mit Hilfe des Verfahrens der "Harmonischen Balance" (Investigation of the Stability of Liquid Propellant Rocket Motors, Using the Method of the "Harmonical Balance"), G. Heinrich and W. Peschka. Gravitational and Related Constants for Accurate Space Navigation, S. Herrick, R. M. L. Baker, Jr., and C. G. Hilton. Alterations in Some Blood Reactions and in the White Cell Count during the Total Eclipse of the Sun in Poland 1954, I. Kaulbersz, R. Bilski, I. Kocyan, A. Ogiński, D. Wiecha, and J. Zbiegień. Optimization Considerations for Orbital Payload Capabilities, H. H. Koelle. Sodium Emission at 140 km, E. R. Manring and J. F. Bedinger. Optimum Burning Program as Related to Aerodynamic Heating for a Missile Traversing the Earth's Atmosphere, A. Miele. The Problem of Variable Thrust, W. N. Neat. Vertical Recovery, Feasibility of the Physical Recovery of Scientific-Research Payloads from Very-High-Altitude Near-Vertical Trajectories, R. T Patterson. Recovery Techniques for Manned Earth Satellites, N. V. Petersen. Attitude Control of a Satellite Vehicle—an Outline of the Problems, R. E. Roberson. Meteor, Jr., a Preliminary Design Investigation of a Minimum Sized Ferry Rocket Vehicle of the Meteor Concept, D. C. Romick, R. E. Knight, and S. Black. Spaces of Potential Visibility of Artificial Satellites for the Unaided Eye, I. Schmidt. Observations from the Manhigh II Balloon Capsule at 30 Kilometers, D. G. Simons. The Probability of Intelligent Life Evolving on a Planet, A. E. Slater. Design and Performance Data of Space Ships with Ionic Propulsion Systems, E. Stuhlinger. Einige Optimalisationsprobleme in der Theorie der Stufenraketen und ein einfaches Verfahren zur Ermittlung der optimalen Parameter der Stufenradeten, M. Subotowicz. U.S. Army Support of Scientific Activities in Astronautics, H. N. Toftoy. The Meteoric Risk to Space Vehicles, F. L. Whipple. Optical and Visual Tracking of Artificial Satellites, F. L. Whipple and J. A. Hynek. Ten Years of Plastic Balloons, O. C. Winzen. The Manhigh II Balloon Operation, O. C. Winzen. Study of the Primary Cosmic Radiation by Using Artificial Satellites of the Earth (In Russian), S. N. Vernov, V. L. Ginzburg, L. V. Kurnosova, L. A. Razorionov, and M. I. Fradkin. Some Problems Relating to the Dynamics of the Flight to the Moon (In Russian), V. A. Yegorov. Visual Observations of the Earth's Satellite in the USSR, A. G. Masevich. On the Establishment of an

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Artificial Satellite of the Earth in Orbit (In Russian), D. E. Okhotsimsky and T. M. Eneiev. Determining the Time of Existence of the Artificial Earth Satellite and Studying Secular Perturbations of its Orbit (In Russian), D. E. Okhotsimsky, T. M. Eneiev, and G. P. Tartynova. Producing the Weightless State in Jet Aircraft, S. J. Gerathewohl, O. L. Ritter, and H. D. Stallings, Jr. The Communication Satellite, R. P. Haviland. Selenoid Satellites, W. B. Klemperer and E. T. Benedikt. On Relativistic Rocket Mechanics, J. M. J. Kooy. Interplanetary Ballistic Missiles—A New Astrophysical Research Tool, S. F. Singer.

Ten Steps Into Space; A Series of Lectures Sponsored by The Franklin Institute, March–May, 1958, in Philadelphia. (*Monograph No. 6.*) Philadelphia, Journal of The Franklin Institute, 1958. 202 pp., illus., diagrs., tables. $4.00.

Contents: Foreword, I. M. Levitt. The Long History of Space Travel, W. Ley. The Rocket and the Reaction Principle, K. Stehling. Rocket Fuels—Liquid and Solid, H. W. Ritchey. Satellite Instrumentation—Results for the IGY, S. Fred Singer. Celestial Mechanics—Orbits of the Satellites, P. Herget. The Explorer, G. Heller. Error Analysis of Single and Two-Force Field Spacecraft Orbits, K. A. Ehricke. Probing the Atmospheres of Venus and Mars, J. I. F. King. Space Medicine—The Human Body in Space, D. G. Simons. Satellites and Travel in the Future, I. M. Levitt.

The Literature of Space Science and Explorations. Compiled by Mildred Benton. (*Bibliography No. 13.*) Washington, U.S. Naval Research Laboratory, Sept., 1958. 264 pp.

This comprehensive bibliography contains annotated references to published unclassified information involving books, periodical articles, and research reports on the more scientific aspects of space exploration, both theoretical and applied. The 2,274 items, which can be located through the author or subject indexes, are listed chronologically by author and cover the period from 1903 through June, 1958. Concentrating on the progress, development, and scientific uses of instrumented vehicles, the bibliography includes all references that could be located on the Vanguard Project, the Russian Sputniks, and the U.S. Army's Explorers. Entries on rocket launching appear only if they apply to satellite problems. The use of manned vehicles is touched upon in several articles, as is the legality of space flight, and space medicine, but the intent has been to exclude psychological and legal aspects.

Space Law, a Symposium. Prepared at the Request of Hon. Lyndon B. Johnson, Chairman, Special Committee on Space and Astronautics, U.S. Senate, 85th Congress, Second Session, Dec. 31, 1958. Washington, U.S. Gov. Print. Off., 1959. 573 pp.

Contents: Preface, E. Galloway. High-Altitude Flight and National Sovereignity, J. C. Cooper. Who Owns the Universe?, O. Schachter. Air Law and Space, W. Heinrich. The Law of Space, C. E. S. Horsford. Some Political Implications of Space Flight, A. W. Hester. International Law and Activities in Space, C. W. Jenks. The Aerial Inspection Plan and Airspace Sovereignty, R. W. Young. Legal Problems of Upper Space, J. C. Cooper. Space Law and Metalaw—A Synoptic View, A. G. Haley. Projecting the Law of the Sea into the Law of Space, C. Ward. Legal Terminology for the Upper Regions of the Atmosphere and for the Space Beyond the Atmosphere, J. C. Hogan. International Law and High Altitude Flights: Balloons, Rockets, and Manmade Satellites, B. Cheng. Decatur's "Doctrine"—A Code for Outer Space, P. B. Yeager and J. R. Stark. Aspects of the Law of Space, M. Aaronson. National Sovereignty at High Altitudes, D. B. Craig. Legal Problems Created by the Sputnik, E. Pépin. The Legal Status of the Airspace in the Light of Progress in Aviation and Astronautics, E. Pépin. The Russian Satellite—Legal and Political Problems, J. C. Cooper. Air Sovereignty Considerations in Terms of Outer Space, R. T. Murphy, Jr. Relationship of the United Nations to Outer Space, In Strengthening the United Nations. Commission to Study the Organization of Peace, A. H. Holcombe, Chairman. Law for the "Heav'n's Pathless Way," Sir L. Munro. The Legal Horizons of Space Use and Exploration, Excerpt from Address by C. S. Rhyne. Space Law, M. Aaronson. Space Penetration, E. Pépin. A Guide to the Study of Space Law, Including a Selective Bibliography on the Legal and Political Aspects of Space, J. C. Hogan. Space Policy Outline Included in the Preceding Item, L. C. Bohn. Principles of International Law in Space Flight, C. E. S. Horsford. Control of Outer Space, M. B. Schofield. Major Aspects of the Problem of Outer Space, L. Becker. The Control of Outer Space and the United Nations, Sir L. K. Munro. Perspectives for a Law of Outer Space, M. S. McDougal and L. Lipson. The Problem of a Definition of "Airspace" (A Memorandum for the 9th Annual Congress of the International Astronautical Federation), J. C. Cooper. The Legal Control of Outer Space, S. M. Beresford. The Community of Law and Science, E. Galloway. Space Law and the Fourth Dimension of Our Age, K. B. Keating. An American View of Jurisdiction in Outer Space, G. J. Feldman. The Responsibility of the States for the Damage Caused by the Launched Space Bodies, I. H. Ph. de Rode-Verschoor. The Law of Outer Space—Scientific and Anthropocentric Considerations, A. G. Haley. Resolution Adopted by the Ninth Congress of the International Astronautical Federation. Open Skies and Open Space, P. W. Quigg. International Order Under Law, Excerpt from Address by W. P. Rogers. Law of Outer Space—Radio Controls Urgently Needed, A. G. Haley. Report of the Committee on the Law of Outer Space, of the Section of International and Comparative Law, American Bar Association (1958). State Sovereignty in Airspace, A. Kislov and S. Krylov. The Legal Status of Outer Space and the Soviet Union, H. G. Neumann. The Artificial Satellite and International Law, G. Zadorozhnyi. On the Question of Interplanetary Law, A. Galina. For Equal Collaboration in the Peaceful Use of Cosmic Space, A. Galina. Digests of Selected Foreign Sources on Space Law, W. Strauss. *Appendixes*: *A*. Freedom of the Air—Early Theories: Freedom; Zone; Sovereignty, S. Latchfod. *B*. United Nations: Texts of Statements and Resolutions on the Peaceful Uses of Outer Space: Statements by H. C. Lodge, U.S. Representative to the General Assembly. Statement by Senator L. B. Johnson. Draft Resolution of 20 Nations, Including the United States, November 13, 1958. Resolution Passed by the First Committee, November 21, 1958, and by the General Assembly, December 12, 1958. Draft Resolution of the U.S.S.R., November 7, 1958. Revised Draft Resolution of the U.S.S.R., November 18, 1958. *C*. Astronautical Societies. *D*. Alphabetical Lists of Authors.

STRUCTURES

High Temperature Effects in Aircraft Structures. Edited by Nicholas John Hoff. (*NATO, AGARD, AGARDograph No. 28.*) New York, Pergamon Press, 1958. 357 pp., illus., diagrs., tables. $12.

Contents: (1) Introduction, N. J. Hoff. (2) External Sources of Heat, M. H. Bloom. (3) Heat Transmission in the Structure, F. V. Pohle. (4) Materials for High-Temperature Aircraft Structures, P. Duwez. (5) Non-Metallic Structural Materials at High Temperatures, C. Gurney. (6) Glass-Like Structural Materials at High Temperatures, I. Peyches. (7) Creep and Relaxation in Metals, N. P. Allan. (8) Creep and Stress Relaxation of Plastics, W. N. Findley. (9) Fatigue of Structural Materials at High Temperature, B. J. Lazan. (10) Thermal Stresses, L. Broglio and P. Santini. (11) Buckling Caused by Thermal Stresses, A. van der Neut. (12) Stress Distribution in the Presence of Creep, N. J. Hoff. (13) Creep Buckling, B. Fraeijs de Veubeke. (14) Influence of Aerodynamic Heating on Aeroelastic Phenomena, R. L. Bisplinghoff and J. Dugundji. (15) Experimental Methods in High-Temperature Structural Research, J. Taylor. (16) Models and Analogs, R. R. Heldenfels.

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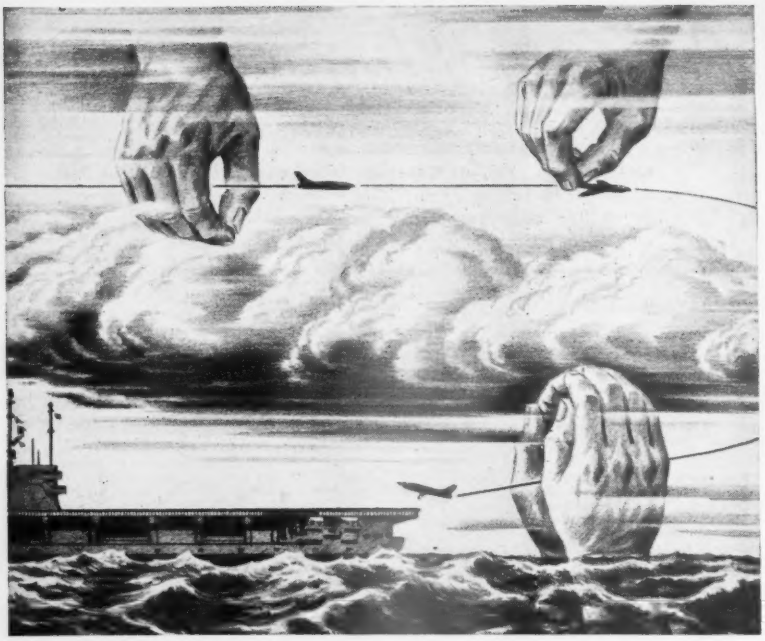

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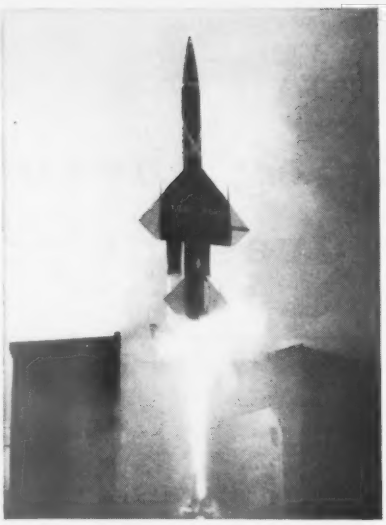

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